

SUPPLEMENTS TO THE REPORT

OF THE

Agricultural Meteorology Branch,

INDIA METEOROLOGICAL DEPARTMENT

FOR THE YEAR

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AGRICULTURAL METEOROLOGY.

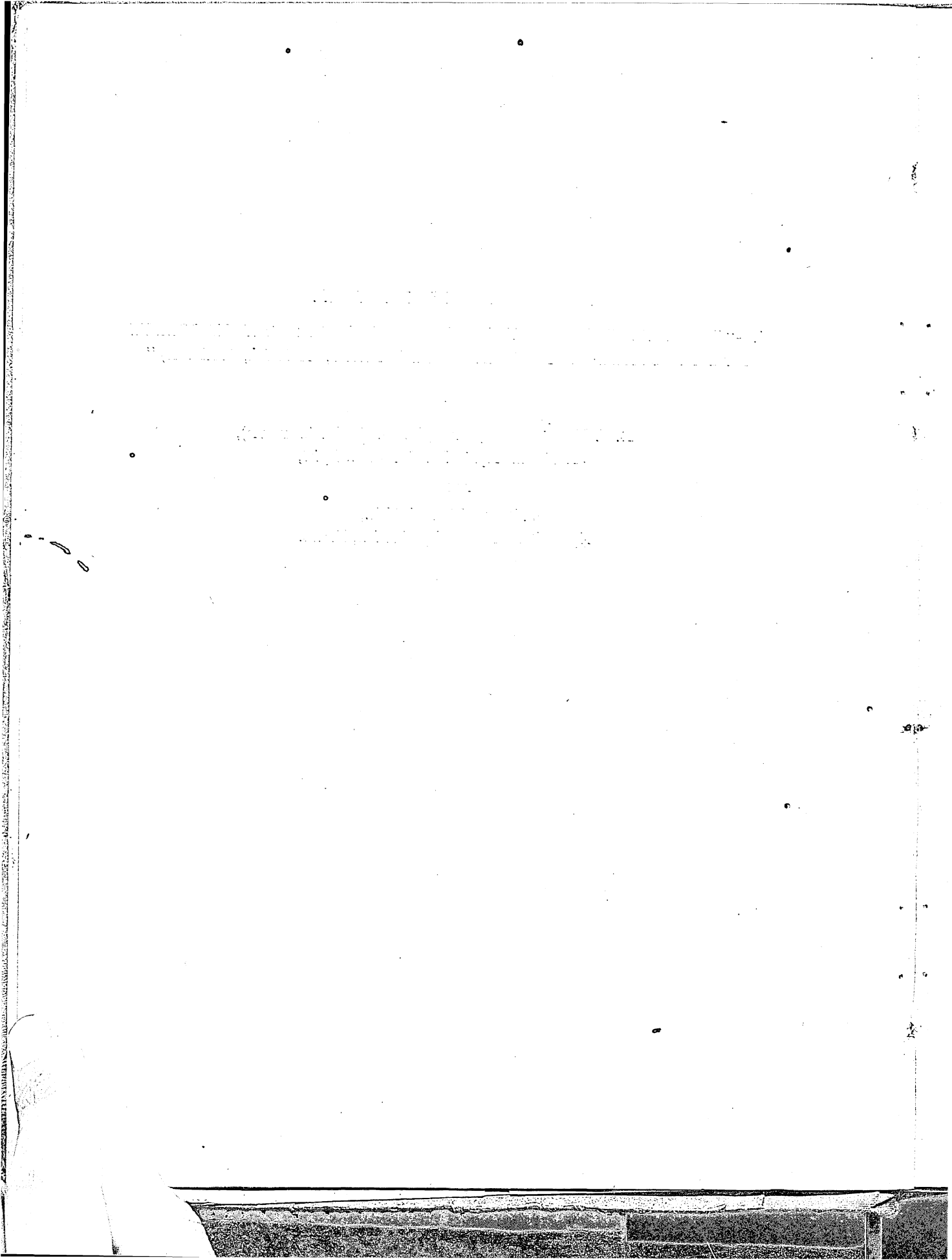
I.—"THE EFFECT OF RAINFALL ON THE YIELD PER ACRE OF COTTON AT THE GOVERNMENT EXPERIMENTAL FARM, AKOLA, (BERAR)"

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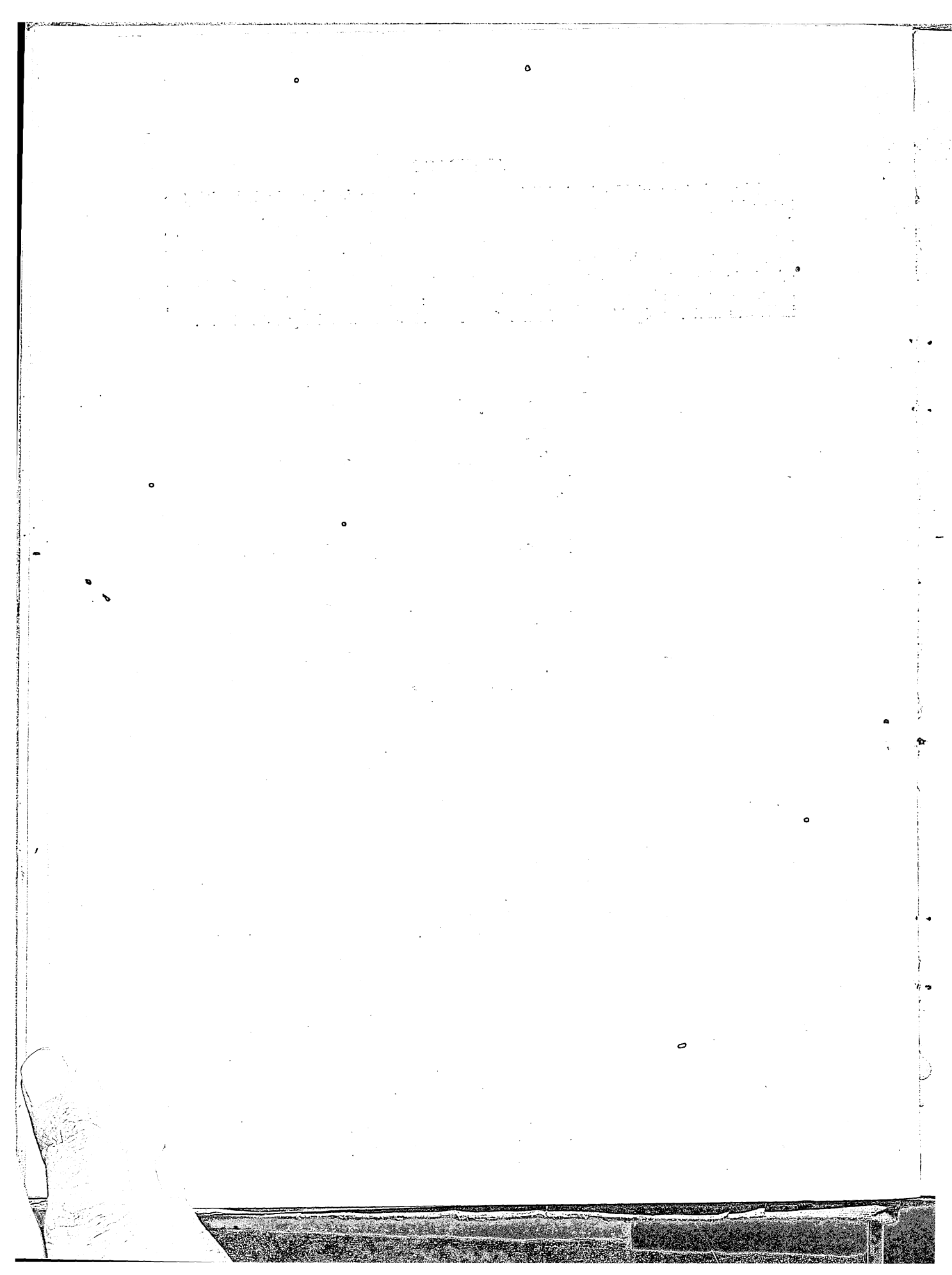
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ABSTRACT

The effect on yield of rainfall in the growing season is investigated with the help of data extending over a period of 28 years commencing from 1908. The season from 22nd May to 23rd October is divided into thirtyone-five-day periods in order to calculate the effect of distribution of rainfall on the yield. The rainfall response curve obtained by using Fisher's well known method does point to an adverse effect of rain in the third week of May, a beneficial effect in June and an adverse effect in July, August and the early part of October; but the analysis, on the whole, indicates that the significance of the rainfall effect is not definitely established.



AGRICULTURAL METEOROLOGY

"THE EFFECT OF RAINFALL ON THE YIELD OF COTTON PER ACRE AT THE GOVERNMENT EXPERIMENTAL FARM, AKOLA (BERAR)"*

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AND

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Berar is one of the chief cotton-growing tracts of India occupying an area of nearly three million acres. Akola is a representative centre of this tract and has a Government Experimental Farm for the study of the cotton crop. The farm was opened in June 1906 and active work began in 1907. The soil of the farm is a deep black loam typical of the Berar cotton tract.

The Akola farm furnishes an interesting series of cotton yield data extending over a period of 28 years, commencing from the season 1907-08. The data consist of the average yield in lbs. of seed cotton per acre at the Akola farm and were kindly supplied by the Director of Agriculture, Central Provinces, Nagpur. The object of this paper is to examine the dependence of the yield of the cotton crop on rainfall during its growth.

The yield data, as already observed, are the average of the farm and not from one particular plot sown to cotton each year. It is expected that the large fluctuations in the yields of cotton may to a considerable extent be attributed to weather conditions prevailing in different seasons. The statistical method employed is that developed by Fisher[1] in his paper entitled "The influence of rainfall on the yield of wheat at Rothamsted".

In studying the effect of rainfall on the yield of cotton a period 22nd May to October 23rd is selected and is divided into 31 periods, each of 5 days, and the total rainfall in each five-day period is computed from the daily rainfall records.[2] A fixed calendar date rather than the date of sowing has been used as a reference point for the season for convenience.

The choice of a five-day period for a unit of time, although arbitrary, is believed to be fine enough to represent the rainfall distribution and also its reaction in general on the growth of the crop and the agricultural operations such as interculture and weeding.

The distribution† of rain for each season has then been expressed by the six rainfall distribution constants a′, b′, c′, d′, e′, f′ of a 5th degree polynomial function of time calculated in the usual manner. These constants, which are given in Table I below, are employed later on as independent variables with which the crop yield is correlated.

* The present investigation was made in the Agricultural Meteorology Section (India Meteorological Department) financed by the Imperial Council of Agricultural Research.

† For a detailed discussion of the rainfall distribution at Akola please see Scientific Notes, India Met. Department, Volume VII, No. 69, by V. Satakopan.

TABLE I

Rainfall Distribution Constants

(Unit : One thousandth of an inch)

Year	a′	b′	c′	d′	e′	f′
1907	620	—122	—157	+ 73	+ 19	— 4
1908	1,108	—170	—249	+103	— 40	— 4
1909	784	— 96	—142	+ 39	— 30	— 5
1910	1,105	— 38	—178	+ 5	— 58	+ 8
1911	623	—129	—109	+ 57	— 13	— 6
1912	608	— 95	—154	+ 84	+ 6	—29
1913	869	—133	—210	+ 67	0	+ 1
1914	859	— 15	—143	— 27	— 72	+23
1915	867	— 18	—177	+ 65	— 12	—46
1916	1,334	— 40	—169	+ 51	+ 22	+30
1917	936	+ 46	— 38	— 45	— 48	— 4
1918	398	—175	+ 15	+ 9	+ 3	— 7
1919	824	—168	— 62	+ 60	— 68	— 1
1920	338	— 37	— 63	+ 27	— 25	— 3
1921	773	— 52	—147	+ 9	— 24	+ 5
1922	954	—135	—240	+113	+ 3	—72
1923	707	+ 60	—139	— 11	— 45	— 5
1924	1,107	+219	—176	—100	+ 8	+50
1925	622	— 88	—119	+ 34	+ 38	— 1
1926	987	—101	—306	+ 89	+ 57	—37
1927	912	+ 22	— 19	+ 47	—164	—70
1928	880	+ 56	— 30	0	— 76	+50
1929	681	—209	— 67	+131	—112	— 7
1930	892	+ 84	—134	—124	— 73	+41
1931	1,130	+256	—106	— 6	— 49	—80
1932	830	— 7	—207	+ 30	+ 21	0
1933	1,215	— 71	—156	+ 4	— 35	+35
1934	1,056	— 67	—318	+ 45	+ 83	— 3

It is interesting to study the variability of these constants over a series of 28 years. A fifth degree polynomial curve is fitted to each of the six series of rainfall distribution constants. The analysis of the data is given in Table II below.

TABLE II

Secular Changes in the Rainfall Distribution Constants

(Unit : One thousandth of an inch)

	a′	b′	c′	d′	e′	f′
Mean	857·82	— 43·68	—142·86	29·61	— 24·43	— 5·03
x'_2	+254·01	+219·11	— 0·14	—77·03	— 11·67	+ 0·76
x'_3	+311·49	— 52·94	—159·39	+39·70	+ 34·11	+13·01
x'_4	+170·05	— 45·14	— 52·00	—16·98	+ 67·71	+13·91
x'_5	— 92·17	—101·54	— 78·36	+20·98	+13·05	+ 5·72
x'_6	+ 73·20	— 53·04	—153·93	+30·38	+ 53·65	— 2·16
S. D.	239·9	109·3	73·6	61·2	47·9	36·5

It is of interest to note that the mean five-day rainfall does not show any trend over the period examined while some of the other rainfall distribution constants show tendencies of slow changes ; this is indicated by the values of x′ *s* when compared with their standard errors given in the last row of the table. For example, b′ shows an upward trend as indicated by its value of x'_2. Significant changes have also occurred in the rainfall distribution constants c′ and e′ as is seen from the values of x'_3 and x'_6 for c′ and x'_5 for e′ respectively. The analysis thus shows clearly that, while the total rainfall at Akola has not changed over the period under consideration, the distribution of it has slightly altered. It is beyond the scope of the present paper to discover for what months the distribution has changed and the causes for the same. Seasonal variation in average daily rainfall at Akola is shown in Fig. 1-*a*.

The average yield of cotton at the Akola farm is given in Table III below :—

TABLE III

Yield of Cotton at Akola

(*Kapas in lbs. per acre*)

Year	Yield	Year	Yield	Year	Yield
1907-08	258	1917-18	179	1927-28	782
1908-09	342	1918-19	218	1928-29	662
1909-10	504	1919-20	771	1929-30	753
1910-11	259	1920-21	55	1930-31	657
1911-12	570	1921-22	513	1931-32	150
1912-13	486	1922-23	216	1932-33	583
1913-14	509	1923-24	456	1933-34	433
1914-15	564	1924-25	334	1934-35	634
1915-16	682	1925-26	393		
1916-17	60	1926-27	378		

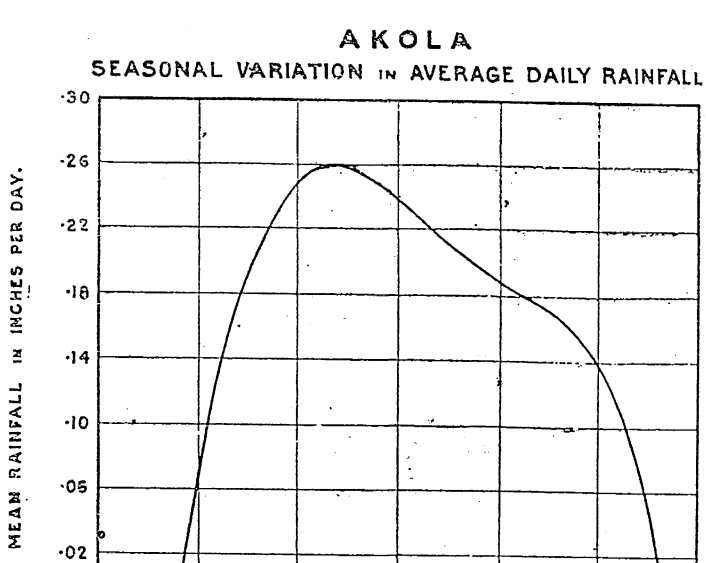

AKOLA
SEASONAL VARIATION IN AVERAGE DAILY RAINFALL.
MEAN RAINFALL IN INCHES PER DAY.
·30
·26
·22
·18
·14
·10
·06
·02
-·02
MAY
JUNE
JULY
AUG.
SEP.
OCT.

FIG. 1-*a*.

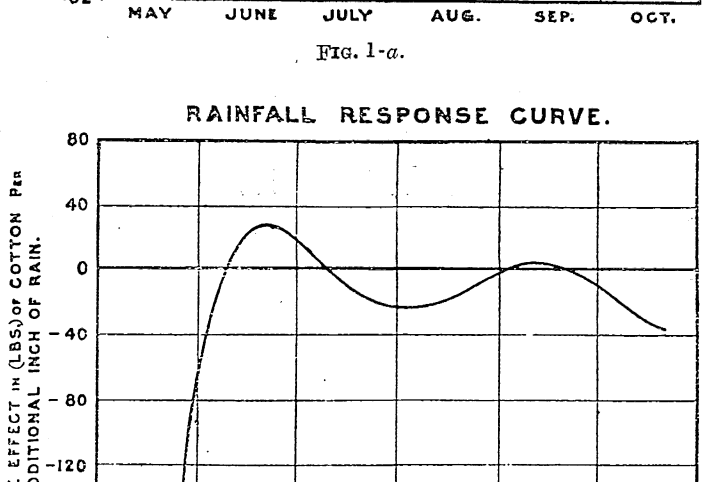

RAINFALL RESPONSE CURVE.
AVERAGE EFFECT IN (LBS.) OF COTTON PER ADDITIONAL INCH OF RAIN.
80
40
0
-40
-80
-120
-160
-200
MAY
JUNE
JULY
AUG.
SEP.
OCT.

FIG. 1-*b*.

The great variability of yield from season to season is well-marked, the mean yield being 443 lbs. of kapas with a coefficient of variability of 48 per cent.

The yields were then examined with a view to study secular changes during the period under investigation. A 5th degree polynomial curve of time was fitted to it. The values of $x'_2\ x_3'.....x'_6$ which are given in Table IV are not significant compared with the residual standard error, indicating the absence of trend in the cotton yields.

TABLE IV

Secular changes in the yield of cotton

Mean	442·89
x'_2	+280·71
x'_3	+131·18
x'_4	+ 18·97
x'_5	—346·52
x'_6	+164·79
S. D.	211·02

Although the yield data do not exhibit any slow changes, the traces of such variation in the rainfall distribution constants necessitate the removal of the effects of such changes to investigate the dependence of yield on the rainfall distribution constants. In Table V are given the direct correlations of the cotton yield with these distribution constants as well as those obtained after removing the effects of secular changes.

TABLE V

Correlation between Yield and Rainfall Distribution constants

	Before eliminating trend	After eliminating trend
a′	—·0782	—·2373
b′	—·1468	—·3415
c′	+·0580	+·1380
d′	+·0821	+·1637
e′	—·3749	—·3751
f′	+·0717	+·0666

It is seen that the correlations, though small, have increased on elimination of the slow changes in the constants. The sums of squares and products of the rainfall distribution constants after correcting for the trend are given in Table VI. Fisher's method[3] was used to solve the six simultaneous equations to obtain the six coefficients of regression of the rainfall distribution constants on the yield. In Table VII is given the matrix of multipliers each of which is the co-factor of the corresponding number in Table VI divided by the value of the determinant.

TABLE VI

Sums of squares and Products of Rainfall Distribution Constants

a′	+1265938					
b′	+ 207647	+262798				
c′	— 172697	— 740	+119196			
d′	— 42582	—106029	— 26566	+82333		
e′	— 11060	— 2988	— 44938	+ 7808	+50417	
f′	+ 14833	+ 8139	+ 7332	—26946	+ 251	+29376

TABLE VII

Matrix of multipliers

a′	b′	c′	d′	e′	f′
+2·72759	— 6·21017	+ 7·90718	— 7·70520	+ 8·43043	— 8·77007
—6·21017	+25·78191	—20·59118	+37·22662	—23·90910	+35·48341
+7·90718	—20·59118	+36·78337	—23·70542	+36·72445	—29·52666
—7·70520	+37·22662	—23·70542	+73·47607	—32·07296	+67·16532
+8·43043	—23·90910	+36·72445	—32·07296	+57·26049	—36·70802
—8·77007	+35·48341	—29·52666	+67·16532	—36·70802	+97·93120

The product moments of yield with the six rainfall distribution constants are calculated after allowing for the secular changes. The six products so obtained, when multiplied by the values of any column of Table VII and added, give the regression coefficients on the corresponding factor.

From the regression coefficients, six coefficients expressing the average benefit or loss in lbs. per acre ascribable to an additional unit of the distribution constant are determined and these coefficients when combined with the usual orthogonal functions of time give a continuous curve showing the average effect in lbs. per acre corresponding to an additional inch of rain at any time during the period considered. This curve is drawn in Fig. 1-*b*.

Cotton is generally sown by the end of the first week of June, usually after the first fall of 2″ of rain. The adverse effect of additional rain in the beginning of the 4th week of May, as seen from Fig. 1-*b* is difficult to explain.* Heavy and continuous rainfall in the latter part of July and August affects the yield adversely as it gives rise to weeds and water-logging. The plants begin to bear in October. Heavy rain at the end of September or the early part of October damages the cotton crop very much. By November about half of the crop is picked.

The equation of yield expressed as a function of the six rainfall distribution constant is: —

$$y = -\cdot4320\,a' + \cdot3278\,b' - 1\cdot2847\,c' + 1\cdot3167\,d' - 3\cdot0329\,e' + 2\cdot0665\,f'.$$

The actual and the calculated yields are shown in Fig. 2. There are comparatively large deviations of the " calculated " from the " actual " for the years 1910-11, 1915-16, 1919-20, 1920-21 and 1931-32, the peculiar features of which are indicated below.

1910-11.—This year the rains began early and were well distributed throughout the growing season. The first part of the season was very favourable but a fall of rain in the first half of November, a period which is not included in the above formula, did serious damage to cotton by washing down many of the mature and immature bolls and flowers.

* Similar adverse effect has been noticed in Gazira (Sudan) by E. M. Crowther[6] who observed that rainfall in May and June exerts a depressing effect on yields of cotton sown in the following July or August at Gazira. He attributes it to the washing off of nitrates formed in the soil. This adverse effect has been also attributed to the possible interference with soil cracks [7] by early rainfall which reduces the rate of drying off of soil and closes the subsoil cracks thus preventing adequate subsoil aeration or water penetration.

It may be mentioned here that high May temperatures are found to have a beneficial effect on yield in the districts of Khandesh, Surat and Ahmedabad in the Bombay Presidency [8].

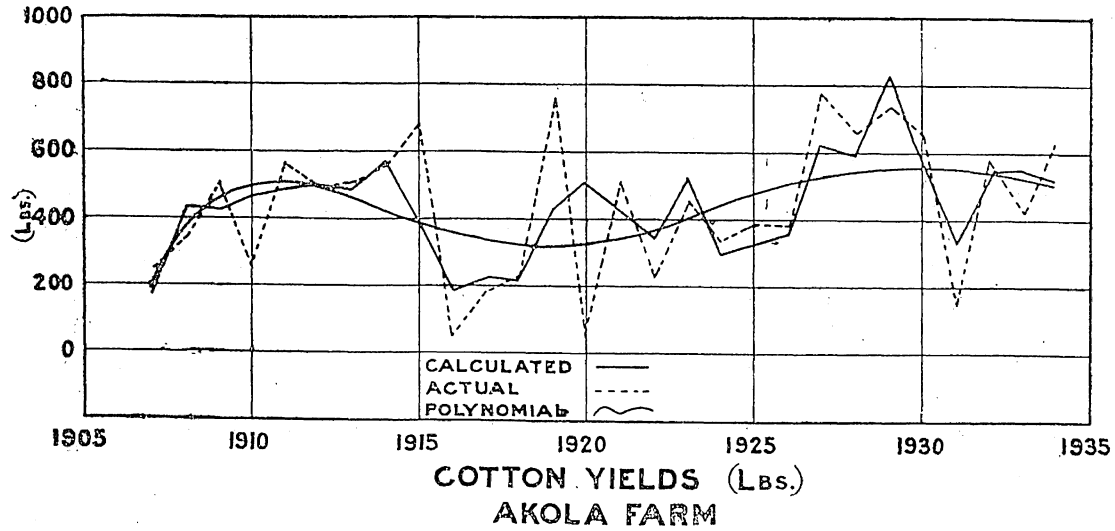


Fig. 2.

The years 1905, 1910 etc. represent the seasons 1905-06, 1910-11 etc.

1915-16.—The records at the farm do not show any special notes except that weeding and hoeing operations were taken advantage of fully because of the opportune breaks in the growing season.

1919-20.—This was a remarkable season for the amount of sunshine. There were only 25 rainy days from the 1st July to the end of September and the rainfall was most opportune.

1920-21.—This was an exceptional year. The total rain was only 10·7″. There was practically no rain for the rest of the cotton season after the first fortnight of July.

1931-32.—The actual yield is even lower than the calculated yield. This may be attributed to the abnormal continuous rain amounting to 9·7″ from 1st to 11th October.

The significance of the dependence of yield on the rainfall distribution constants can be tested by partitioning the total sum of squares of yield as indicated in Table VIII.

TABLE VIII

Analysis of Variance

	D. F.	Sum of squares	Mean square
Due to—			
Regression	6	334196	55699
Polynomial	5	243602	48720
Residual	16	645451	40341
Total	27	1223249	45306

The sum of squares due to 27 D. F. for the 28 years can be split up into that due to polynomial with 5 D. F. and the remaining as due to deviations from the polynomial with 22 D. F. The 22 D. F. can be further split up into 6 due to regression and 16 due to deviations from the regression, the mean square due to the latter serving as a basis for testing whether the mean square due to regression is significant. The analysis shows that the mean square due to regression is not significantly greater than that due to residual variance. The value of the multiple correlation R is ·58, while that required for significance[4] is ·71. It may, however, be observed that the regression coefficient of yield on e′ is significant compared to its standard error.

The analysis, on the whole, indicates that the significance of the rainfall effect is not definitely established from these data extending over a short period of 28 years. It is, however, interesting to note that the curve showing the average effect in lbs. ascribable to an additional inch of rain appears more or less to agree with the usual impressions of the cultivators as regards the influence of rain on the yield of cotton. In this connection a paper[5] on "Cotton prospects on the Nagpur Agricultural College Farm" by J. C. McDougall is of interest.

In conclusion, the authors wish to express their best thanks to Dr. L. A. Ramdas, Agricultural Meteorologist, Poona, for his help in the preparation of his paper.

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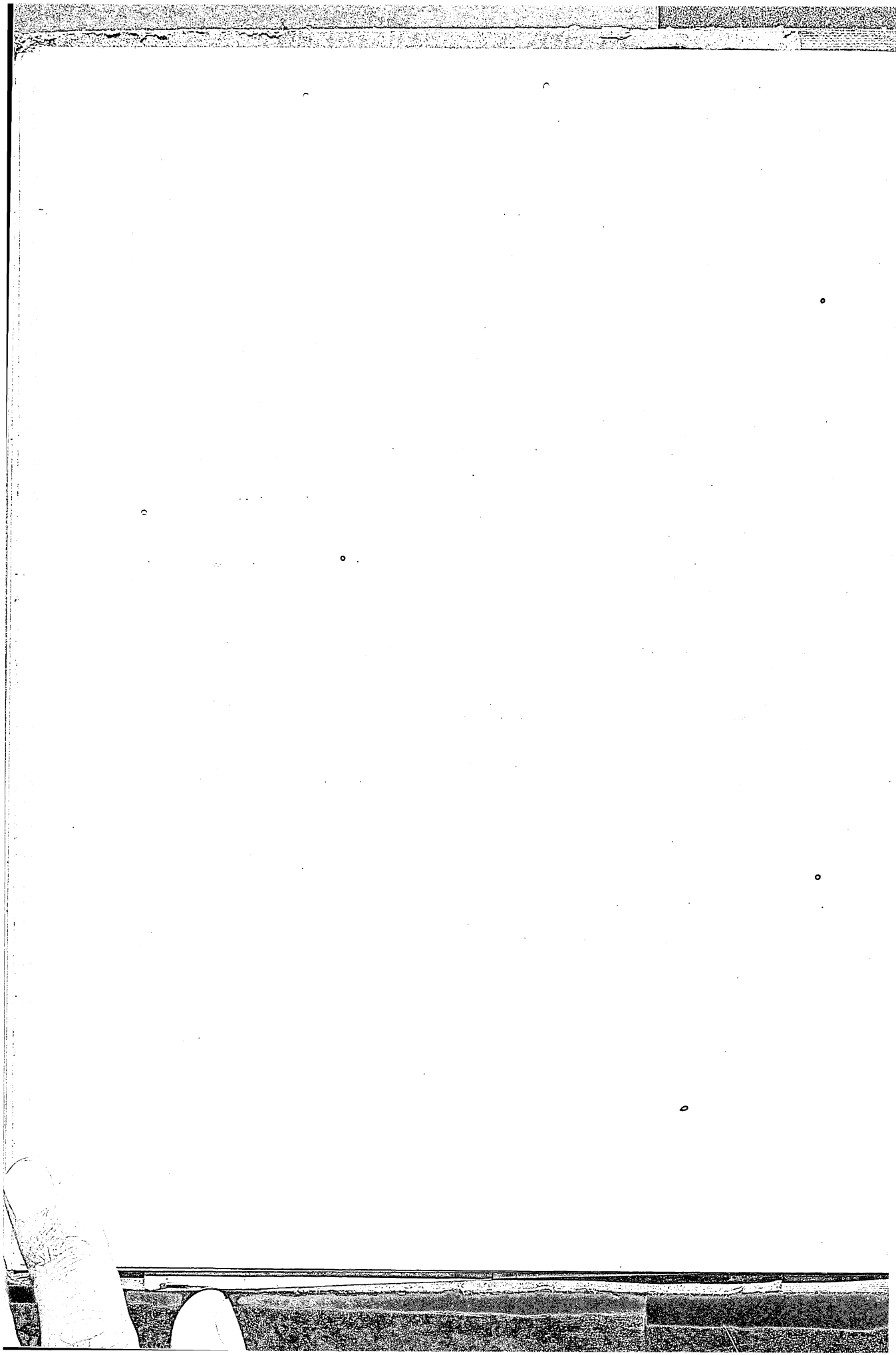
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" Influence of weather on the yield of cotton in the Bombay Presidency " (*vide* paper IV of these supplements, pp. 41—77).



AGRICULTURAL METEOROLOGY.

II.—NOTES ON THE ANALYSIS OF YIELDS OF CROPS AT THE GOVERNMENT EXPERIMENTAL FARMS IN THE CENTRAL PROVINCES AND IN THE BOMBAY PRESIDENCY.

NOTES ON THE ANALYSIS OF YIELDS OF CROPS AT THE GOVERNMENT EXPERIMENTAL FARMS IN THE CENTRAL PROVINCES AND IN THE BOMBAY PRESIDENCY

The limitations of the yield estimates of crops as reported in the season and crop reports of various provinces for investigating the influence of weather factors are well known. The yield data of the experimental farms, however, are expected to be accurate but unfortunately they are available for comparatively shorter periods of years. As a preliminary, an attempt has been made to study the seasonal variability of some crops grown at six experimental farms in the Central Provinces and seven experimental farms in the Bombay Presidency extending over periods varying from 10 to 26 years.

In Tables I and II are given the average yields of varieties of crops at different centres and their seasonal variation. Inter-dependence of soil type, distribution of rainfall and other meteorological elements, cropping zones, varietal response and seasonal variability of yields are expected to be indicated by such a study.

It is interesting to note that while in the Central Provinces the coefficient of variability of wheat ranges from 17 to 35% it is of the order of 45% in the Bombay Presidency. In the case of rice it varies from 12 to 34% in both the provinces. The variability of cotton in the Bombay Presidency ranges from 27 to 39% while in the Central Provinces and Berar it varies between 37 to 54%. The variability of jowar is of the order of 20 to 53% while for gram it varies from 25 to 41% in both the provinces.

TABLE I

Bombay Presidency.

Crop	Farm	Period	Yield in lbs.	coefficient of variability
Jowar.		*Variety.*		
Maldani Rabi	Mohol	1922-23 to 1931-32	431·8	20·6%
Aispuri	Jalgaon	1913-14 to 1931-32	824·9	52·6%
Goda Garya	Jalgaon	1922-23 to 1931-32	1,134·7	53·4%
Fulgar yellow	Dharwar	1907-08 to 1932-33	988·6	40·2%
Jowar	Surat	1907-08 to 1932-33	848·6	22·7%
Cotton.				
N. R. Cotton	Jalgaon	1913-14 to 1931-32	504·7	36·6%
Local seed cotton	Jalgaon	1921-22 to 1931-32	430·1	38·5%
Kumpta Cotton	Dharwar	1908-09 to 1932-33	475·0	36·5%
Cotton	Surat	1907-08 to 1932-33	483·6	27·0%
Rice.				
Patni Upland	Ratnagiri	1923-24 to 1932-33	1,667·7	31·3%
Waksal Lowland	Ratnagiri	1923-24 to 1932-33	2,032·4	34·4%
Kolamba—42	Karjat	1921-22 to 1930-31	2,814·3	12·6%
Kolamba—42	Karjat (season plot).	1923-24 to 1935-36	2,713·0	19·1%

TABLE I—*contd.*

Crop	Farm	Period	Yield in lbs.	Coefficient of variability
Wheat				
Bansi	Jalgaon	1913-14 to 1931-32	673·7	46·4%
Local Red	Dharwar	1909-10 to 1932-33	491·3	44·9%
Gram				
Yellow gram	Jalgaon	1913-14 to 1931-32	613·4	40·8%
Gram	Dohad	1907-08 to 1932-33	630·8	33·3%
Ground nut				
Spanish pea nut	Jalgaon	1917-18 to 1931-32	1340·3	32·3%
Maize	Dohad	1907-08 to 1932-33	1005·1	42·3%

TABLE II

Central Provinces

Crop	Farm	Period	Yield in lbs.	Coefficient of variability
Wheat	Powarkheda—			
	(AO 13)	1917-18 to 1933-34	502·1	25·7%
	(A 45)	1917-18 to 1933-34	494·3	24·6%
	Tharsa	1913-14 to 1931-32	669·7	17·3%
	Chindwara	1920-21 to 1934-35	607·4	35·6%
	Labhandi	1918-19 to 1934-35	603·2	17·8%
	Adhartal	1913-14 to 1933-34	598·2	25.8%
Gram	Powarkheda	1917-18 to 1933-34	493·5	24.7%
	Chindwara	1920-21 to 1924-25	599·7	30·0%
	Adhartal	1912-13 to 1933-34	697·1	33·4%
Paddy	Labhandi	1918-19 to 1934-35	1699·8	16·6%
	Adhartal	1913-14 to 1933-34	1314·9	30·7%
Cotton	Khandwa	1925-26 to 1934-35	424·4	36·5%
	Akola	1907-08 to 1934-35	443·0	48·0%
	Chindwara	1920-21 to 1934-35	337·6	53·5%
Jowar	Khandwa	1925-26 to 1934-35	360·4	40·5%
Ground Nut	Khandwa	1925-26 to 1934-35	807·7	18·8%
Til	Powarkheda	1917-18 to 1933-34	185·1	44·0%

When the yield data are available only for short periods statistical analysis by the usual correlation method is inadvisable ; in such cases an examination of the data side by side with available notes on the life-history of the crop and the sequence of weather during each of the seasons concerned may be useful for summarising the available information. This is being attempted.

AGRICULTURAL METEOROLOGY

III.—"INFLUENCE OF WEATHER AND PRICES ON THE COTTON ACREAGE IN THE BOMBAY PRESIDENCY"

BY

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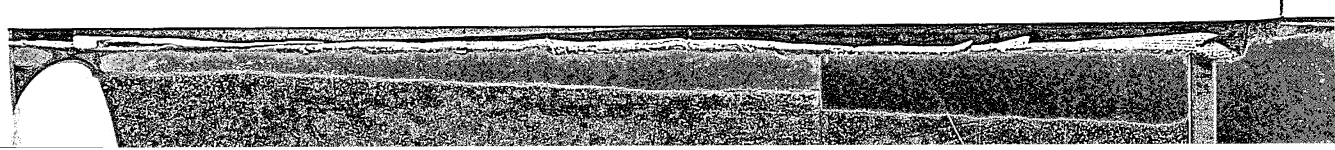
ABSTRACT.

The influence of rainfall during the sowing season and of the prices of cotton prevailing during the pre-sowing season on the acreage of cotton for the 8 districts of the Bombay Presidency has been investigated in this paper.

The data extend over a period of 43 years commencing from 1889-90. The acreage under cotton over this period shows a general tendency to increase. This is mostly caused by the increasing prices of cotton ; of late, however, certain districts have begun to show a decreasing tendency in the area because of fall in prices of cotton. The coefficient of variability of cotton acreage is least in Khandesh (8%). Dharwar comes next with 13%. Other districts have a variability of 15% to 30%, excepting Ahmednagar which has the highest variability of 55%.

Bombay " Broach " prices which represent the average of January and July wholesale prices of exported cotton at Bombay are also available for the above period while the prices of important varieties of " Broach," " Khandesh " and " Dharwar ", which are the average prices for seven months January to July, are available only from the year 1899 onwards. It was considered desirable to use the corresponding varietal prices for the different cotton growing districts for investigating their influence on the acreage of cotton instead of the prices of raw cotton " Broach " at Bombay.

Acreage under cotton in the Ahmednagar district (sowing season June—July) shows a significant positive correlation with June rainfall, while prices do not seem to affect the acreage under cotton in this district. July and August rainfall in Belgaum, and August rainfall in Bijapur (sowing season in Belgaum and Bijapur August—September) show a significant positive correlation with cotton acreage. The cotton acreages in these districts, as in the case of Ahmednagar, do not seem to be significantly influenced by prices. Cotton acreage in the Surat district (sowing season June—July) shows a significant negative correlation with July rains. High prices of cotton are seen to increase the cotton acreage significantly in the districts of Ahmedabad, Broach, Surat, Khandesh and Dharwar.



AGRICULTURAL METEOROLOGY

INFLUENCE OF WEATHER AND PRICES ON THE COTTON ACREAGE IN THE BOMBAY PRESIDENCY*

BY

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1. *Introductory.*—The fluctuations in the acreage under a crop from year to year depend upon a number of factors. The most prominent among these factors may be classified under two heads, *viz.*, "weather" and "the market". In the first place the weather conditions have their reaction on the acreage because different types of weather during the sowing season may suit different crops provided the same type of soil can grow them. Irwin in his paper on "Crop forecasting and the use of meteorological data in its improvements"[1] has reviewed the work of various investigators on this aspect of the problem and has shown how forecasts of crop acreage and yield may be made on the basis of weather conditions which, where adequate data exist, are more accurate than those arrived at by the subjective methods used in the official forecasts of most countries. Pioneer work of this nature has also been done in India by Jacob[2] and Unakar[3] with reference to the wheat crop of the Punjab.

The second important controlling factor, *viz.*, "market prices" has its reaction on the acreage by influencing the mind of the cultivator as to the most profitable way of allotting his land to different crops. Naturally, this factor may be expected to influence the commercial crops more directly than the food crops.

In an attempt to analyse the relation between the acreage and the two types of influence mentioned above, we may consider the most representative element in each case. For instance, so far as its reaction on the acreage of the crop is concerned, the rainfall of the sowing season can be taken to be a representative factor indicating in general the weather conditions. Similarly, the price of the crop concerned may be taken to be an index of the economic factors which affect the acreage under that crop.

The object of this paper is to investigate the influence of the rainfall of the sowing season and the prices prevailing during the pre-sowing season† on the acreage of cotton in the Bombay Presidency.

Cotton is an important money crop of India occupying nearly 16 million acres, about one-fourth of which is in the Bombay Presidency. Fig. 1 shows the distribution of cotton in different provinces of India for the year 1931-32. Fig. 2 again shows the distribution of the crop inside the presidency amongst the various districts for the same year.

The cultivation of cotton in the Bombay Presidency is concentrated in four tracts, *viz.*, (1) South Gujarat, (2) Karnatak, (3) North Gujarat, and (4) the Deccan

* This investigation was made in the Agricultural Meteorology Section (India Meteorological Department, Poona) financed by the Imperial Council of Agricultural Research.

† We neglect for the present the influence of other factors like intensity of "Population", number of cattle available for field labour, etc.

Each of these is defined by the character of the soil and the season and consequently also by the type of cotton grown. Table 1 gives the type of soil, annual rainfall, variety of cotton grown, and the times of sowing, etc., of cotton in these tracts which are mentioned in the order of excellence of the quality or staple-length of the cotton grown. Figs. 3, 4-*a* and 4-*b* show the seasonal distribution of maximum and minimum temperatures and of monthly rainfall of representative stations in the cotton growing tracts. The temperature data are the five day normals whereas the rainfall data are the normal monthly rainfalls.

The district is taken as the unit of area in the present investigation. It is believed to be comparatively more homogeneous with respect to soil, climate, and economic condition than the divisions (tracts) or trade blocks comprising two or more districts. Hence in the present paper, the study is carried out for all the important cotton growing districts in the Bombay Presidency as follows :—

District.	Tract to which it belongs.
Ahmedabad	North Gujarat.
Broach	South Gujarat.
Surat	South Gujarat.
Khandesh (East and West)	The Bombay Deccan.
Ahmednagar	The Bombay Deccan.
Belgaum	Karnatak.
Bijapur	Karnatak.
Dharwar	Karnatak.

COTTON ACREAGE IN INDIA
(1931—1932.)
TOTAL. 14,487,000 ACRES.

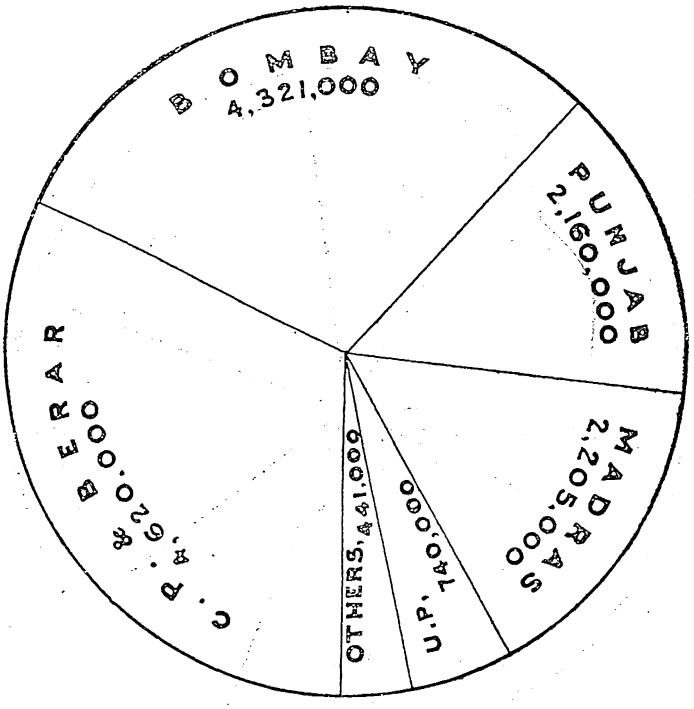


Fig. 1.

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COTTON ACREAGE
IN THE BOMBAY PRESIDENCY
TOTAL. 4,065,000 ACRES
(1931—1932)

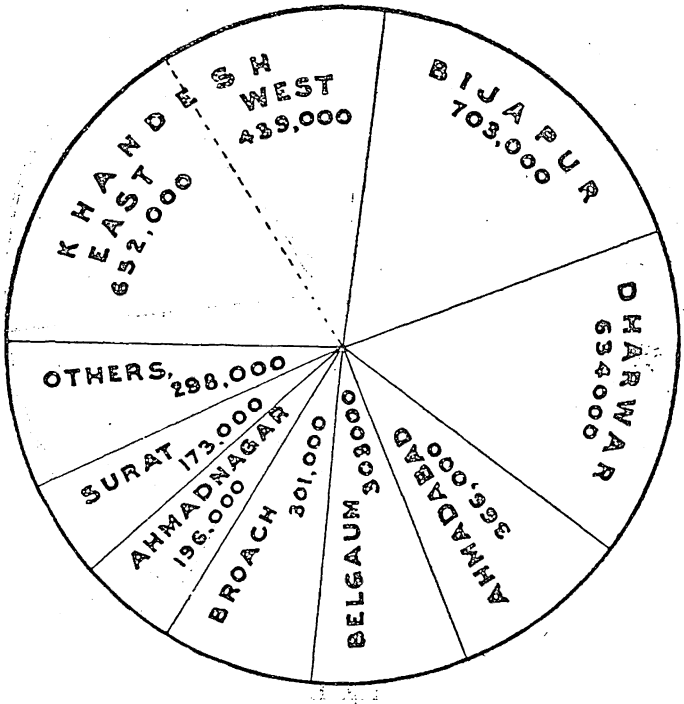


Fig. 2.

TABLE I

Tract	Soil	Annual rainfall	Variety of cotton	Sowing time	Picking
South Gujarat	It comprises the Broach and Surat districts. Soil is deep black derived from trap with a little granite or gneiss. It is supposed to be the result of alluvium brought down by the Tapti and Narbada rivers.	30″-40″ most of which falls between the middle of June and beginning of October.	Broach belonging to Herbaceum species. It is the best indegenous long staple cotton.	June July	February March
Karnatak	It comprises the Belgaum, Dharwar and Bijapur districts. The north and western side of Belgaum has trap in many places covered with laterite and the southern side has granite and gneiss. Dharwar and part of Bijapur have mostly granite and gneiss formation. The cotton in this tract is confined to black clay or red loam soils.	20″-30″; this tract is in the region of two monsoons. The rain is received both earlier and later in the year than in the above tract. The better distribution in time of the annual rainfall makes up for the smaller amount as compared with the first tract.	Local indigenous variety known as Kumpta (Herbaceum) and another Dharwar American belonging to Hirsutum species. They are long staple cottons.	August September	February March
North Gujarat	Ahmedabad is an important cotton growing district in this tract. The soil is alluvial of Indo-Gangetic type and is sandy in character with colour varying from light ash to rich brown. The soil is called Goradi soil.	25″-30″ distributed over 3½ months, *viz.*, middle of June to end of September.	The main agricultural varieties are known as Lalio and Wagud both of Herbaceum species.	July August	February March
Deccan tract	It comprises the Khandesh, Nasik, Poona, Satara, Ahmednagar and Sholapur districts. Khandesh district is an important cotton producing area. The soils are deep black derived from trap.	20″-30″ falling within 3½ months, *viz.*, middle of June to the beginning of October.	Jari or Varadi belonging to Neglectum species short staple cotton.	June July	November. December.

It is seen from Fig. 2 that these eight districts grow, between them, over 90 per cent of the cotton crop of the Bombay Presidency.

2. *Sources of data. Acreages.*—The figures for acreage under cotton for various districts are available in the annual reports of the Department of Land Records

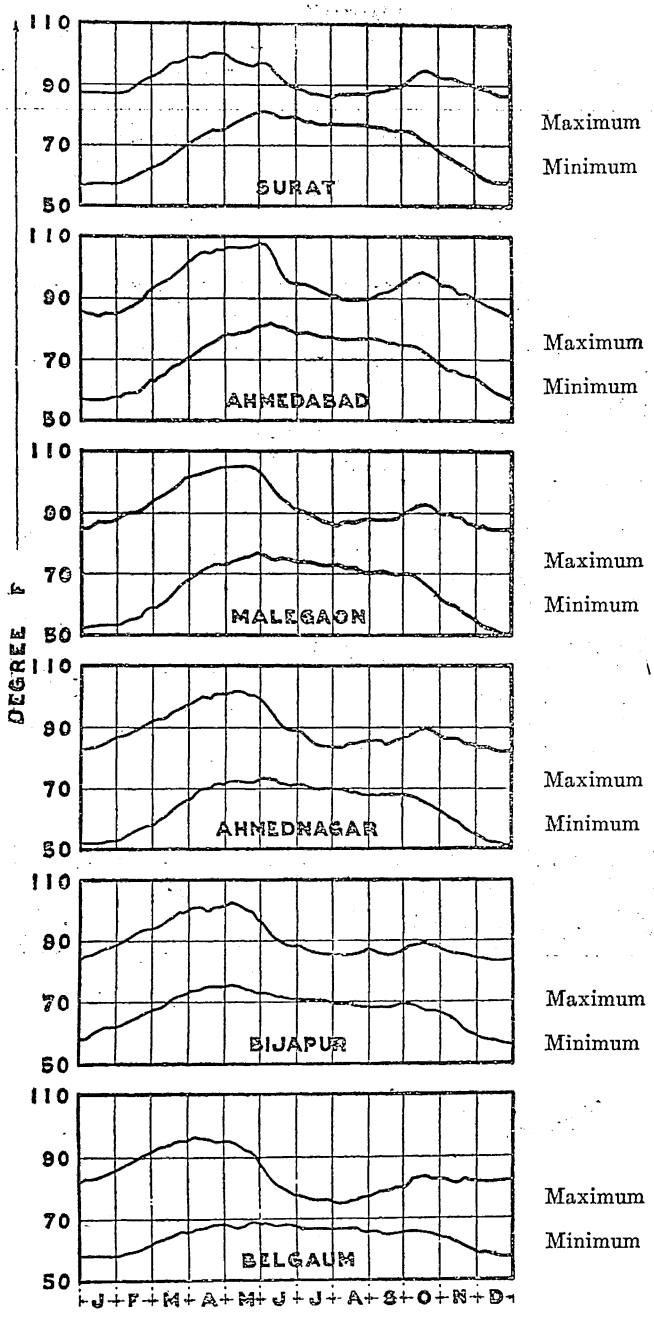


Fig. 3 { Maximum Temperature and Minimum Temperature.

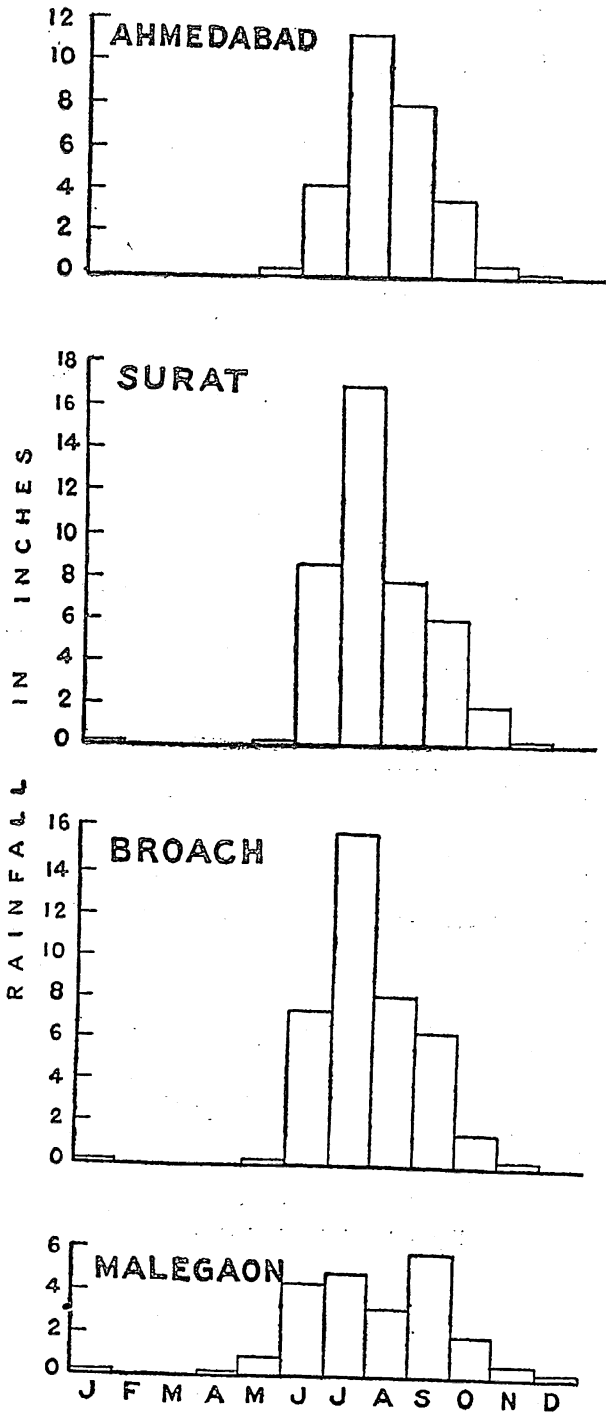


Fig. 4-*a* Rainfall in inches.

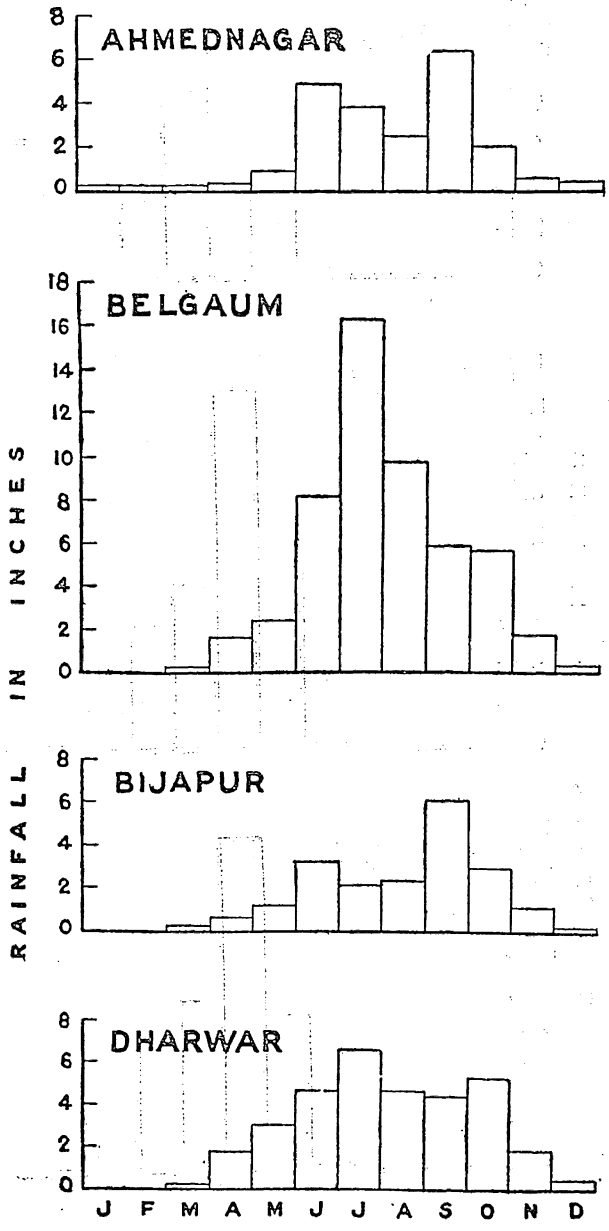


Fig. 4-*b* Rainfall in inches.

and Agriculture from 1889-90 to 1902-03 and thereafter in the Season and Crop Reports of the Bombay Presidency. From the records of transfers of areas available in the "Agricultural Statistics of India" it is found that, in the Bombay Presidency, the districts have remained more or less uniform except for Belgaum and Bijapur where about 21,000 acres of cultivated land were transferred from Belgaum to Bijapur in the year 1905-06. This is reported to be due to the transfer of a village from Athni Taluk in Belgaum to Bijapur district.* This transfer does not seriously affect the uniformity of the cotton acreage series in either Belgaum or Bijapur because the difference in either case will be of the order of two to three thousand acres of land under cotton as against the average of 200,000 and 500,000 acres over the districts as a whole. The acerage data for different districts are given in Table 2.

TABLE 2.

Area under cotton in thousands of acres

	Ahmed-abad	Broach	Surat	Khan-desh	Ahmed-nagar	Bel-gaum	Bija-pur	Dhar-war
1889-90 . .	299	263	93	1013	63	143	371	484
1890-91 . .	364	312	107	1148	64	145	373	450
1891-92 . .	352	255	94	1097	36	106	224	245
1892-93 . .	229	225	80	1075	93	145	313	442
1893-94 . .	299	274	111	1065	59	153	334	452
1894-95 . .	275	212	96	986	30	186	380	472
1895-96 . .	276	271	94	925	74	198	338	495
1896-97 . .	282	216	103	1073	76	160	450	387
1897-98 . .	238	234	70	846	2	148	179	482
1898-99 . .	316	187	78	1103	42	134	305	410
1899-1900 . .	23	63	64	1022	65	114	243	415
1900-01 . .	105	185	76	924	75	148	298	430
1901-02 . .	215	258	95	1287	92	106	204	467
1902-03 . .	139	222	92	1119	110	159	422	530
1903-04 . .	307	234	99	1288	144	225	551	566
1904-05 . .	341	275	148	1202	80	183	456	582
1905-06 . .	371	301	137	1430	120	129	565	531
1906-07 . .	355	274	131	1429	199	253	459	553
1907-08 . .	310	288	153	1263	145	229	544	609
1908-09 . .	243	262	127	1216	36	217	371	601
1909-10 . .	254	269	139	1244	171	233	609	608
1910-11 . .	339	281	164	1380	214	278	641	686
1911-12 . .	67	317	177	1440	89	213	698	615
1912-13 . .	279	245	122	1354	18	282	635	633
1913-14 . .	341	259	146	1465	155	172	387	660
1914-15 . .	284	238	123	1417	273	258	694	567
1915-16 . .	198	262	120	1181	120	166	422	535
1916-17 . .	362	293	140	1406	161	269	711	632
1917-18 . .	408	318	165	1391	117	280	791	740
1918-19 . .	327	307	175	1344	25	209	649	683
1919-20 . .	498	319	161	1382	86	173	426	585
1920-21 . .	431	286	160	1274	3	173	410	595
1921-22 . .	263	221	124	1139	60	160	261	442
1922-23 . .	385	298	148	1309	197	200	328	556
1923-24 . .	546	329	169	1337	147	299	718	681
1924-25 . .	556	327	199	1393	143	339	867	745

* *Vide* Season and Crop Reports, 1905-06, page 4.

Area under cotton in thousands of acres—contd.

	Ahmed-abad	Broach	Surat	Khan-desh	Ahmed-nagar	Bel-gaum	Bijapur	Khar-war
1925-26 . .	657	344	201	1395	242	270	836	742
1926-27 . .	367	284	161	1324	114	265	717	665
1927-28 . .	421	308	172	1310	276	304	711	705
1928-29 . .	481	328	200	1274	257	328	746	753
1929-30 . .	553	324	187	1244	184	221	678	735
1930-31 . .	377	286	168	1112	116	202	464	570
1931-32 . . .	366	290	173	..	196	303	703	634

Prices.—The price statistics for cotton are available from two sources, namely (1) "Index number of Indian prices" published by the Department of Commercial Intelligence and Statistics, Calcutta, and (2) the Season and Crop Reports of the Bombay Presidency. The former publication gives in Table V, Col. 6 the prices of raw cotton "Broach" per candy of 784 lbs. which are the averages of two quotations, one in January and another in July, of wholesale prices of export at Bombay based on the Bombay Chamber's current quotations. This series is available from the year 1861 onwards.

The Season and Crop Report of the Bombay Presidency contains a table giving the wholesale prices of cotton per bale of 400 lbs. for three important varieties, "Broach", "Khandesh" and "Dharwar", being the averages of prices for seven months January to July. This table gives also the five-year averages of such prices for comparison with the current prices; the above data are available from 1904 only but from the five-yearly averages, the corresponding prices can be obtained from the year 1899.

For this investigation the price data were extracted for 43 years (1889—1931) from the first source and for the available 33 years from the second and the figures reduced to "seers per rupee". These series are given in Table 3.

TABLE 3

Price of Cotton (seers per rupee)

	Bombay Broach	Broach Variety	Khandes Variety	Dharwar Variety
1889 . . .	1·67			
1890 . . .	1·68			
1891 . . .	1·82			
1892 . . .	2·05			
1893 . . .	1·64			
1894 . . .	1·82			
1895 . . .	1·94			
1896 . . .	1·81			
1897 . . .	2·00			
1898 . . .	2·24			
1899 . . .	2·60	2·15	2·41	2·56

Price of Cotton (seers per rupee)—contd.

	Bombay Broach	Broach Variety	Khandesh Variety	Dharwar Variety
1900 . . .	1·79	1·75	1·94	1·67
1901 . . .	1·82	1·80	2·35	1·92
1902 . . .	1·85	1·83	2·16	1·82
1903 . . .	1·89	1·77	2·30	1·85
1904 . . .	1·58	1·31	1·63	1·45
1905 . . .	1·81	1·84	2·22	1·90
1906 . . .	1·56	1·47	1·94	1·55
1907 . . .	1·57	1·49	2·16	1·60
1908 . . .	1·59	1·54	2·02	1·64
1909 . . .	1·62	1·54	1·80	1·57
1910 . . .	1·29	1·19	1·45	1·23
1911 . . .	1·15	1·09	1·27	1·09
1912 . . .	1·39	1·40	1·55	1·35
1913 . . .	1·27	1·31	1·58	1·45
1914 . . .	1·35	1·34	1·85	1·44
1915 . . .	1·91	1·82	2·63	1·82
1916 . . .	1·34	1·40	1·72	1·27
1917 . . .	0·85	0·90	1·17	0·88
1918 . . .	0·60	0·54	0·71	0·54
1919 . . .	0·62	0·77	0·98	0·83
1920 . .	0·78	0·78	1·43	0·84
1921 . . .	1·21	1·20	1·89	1·18
1922 . . .	0·76	0·76	1·04	0·78
1923 . . .	0·78	0·71	0·90	0·70
1924 . . .	0·67	0·65	0·71	0·63
1925 . . .	0·85	0·82	0·85	0·85
1926 . . .	1·13	1·09	1·31	1·14
1927 . . .	1·32	1·20	1·10	1·41
1928 . . .	0·98	0·98	1·19	1·00
1929 . . .	1·15	1·12	1·44	1·16
1930 . . .	1·58	1·53	1·90	1·50
1931 . . .	1·90	1·96	2·41	1·94

3. *Analysis of data.*—The figures for area under cotton extending over a period of 43 years commencing from 1889-1890 for the important cotton growing districts of the Bombay Presidency are given in Table 2 in thousands of acres. In the case of Khandesh which was separated in 1906-07 into East and West Khandesh the sum of acreages for both the East and West has been taken so as to make the series uniform.

The acreage series for each district given in Table 2 has been subjected to curve fitting with a view to discover any secular changes that may exist. The method consists in fitting orthogonal polynomials to the series as developed by Fisher [4]. In all cases a cubic curve was fitted except for Khandesh to which a 4th degree curve was thought necessary. Table 4 gives the values of α's for each series with their standard residues.

TABLE 4

Secular changes in the acreage under cotton (43 years commencing from 1889-90)

	Ahmed-abad	Broach	Surat	Khan-desh	Ahmed-nagar	Bel-gaum	Bija-pur	Dhar-war
Mean .	328	268	134	1229	116	206	500	567
S. D. .	127	51	38	162	73	63	189	115
.	+461·6	+177·2	+209·4	+627·9	+256·0	+282·1	+778·1	+577·0
.	+248·3	+41·9	+3·6	−427·2	+5·9	−13·4	−131·0	−122·8
.	−209·9	−106·0	−35·9	−276·8	+49·3	−12·0	−93·7	−51·4
.				+223·5				
Standard residue.	96	41	21	101	63	48	150	73

TABLE 5

Secular changes in the acreage under cotton (33 years commencing from 1899-1900)

	Ahmed-abad	Broach	Surat	Khan-desh	Ahmed-nagar	Bel-gaum	Bija-pur	Dhar-war
Mean .	338	276	146	1284	134	223	552	608
S. D. .	142	53	35	130	72	62	182	92
κ'_2 .	+558·4	+183·3	+153·6	+108·4	+143·1	+201·1	+539·3	+324·3
κ'_3 .	−87·4	−98·1	−39·3	−487·3	+44·4	−52·9	−189·5	−126·2
κ_4 .	−25·9	+76·8	+37·8	+88·0	+86·3	+76·6	+205·7	+97·8
Standard residue.	106	37	20	99	69	51	154	70

The significance of secular changes can be tested by comparing the values of κ's with the standard residue. Any value of κ' more than twice the standard residue can be taken to indicate a significant secular trend along the corresponding degree of the polynomial. It is found that secular changes have taken place in the cotton acreages in all the districts of Bombay Presidency. The values of κ'_2 are all positive and are found to be 4 to 10 times their respective standard residues. This shows that a very significant increase in the cotton acreages has taken place in all the districts of the Bombay Presidency during the period concerned. Apart from the conspicuous straight line trend referred to above, some districts also show significant trends of higher order as indicated by the values of κ'_3 and κ'_4. The nature of these changes can be seen in polynomial curves shown in figures 6-*a* and 6-*b*.

The causes of these secular changes cannot be fully accounted for unless a comprehensive study of the total cultivated area and also of the area under different crops is taken up in conjunction with such economic factors as prices. One example of the influence of a competing crop is to be found in the case of Jowar crop in Khandesh district. The acreage under jowar in Khandesh has diminished during

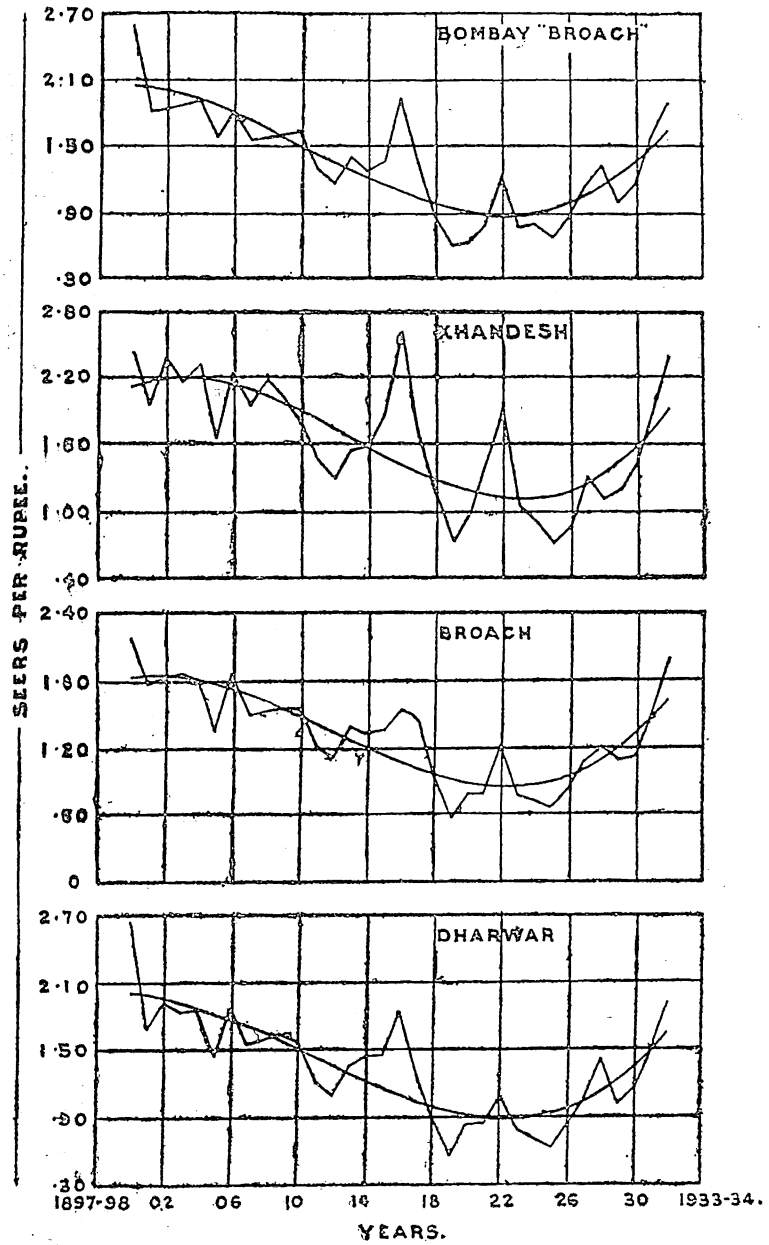


Fig. 5.

Cotton Prices { Actual ——— Polynomial ~~~

improved communication, better facilities for transport, and increase in the ginning and pressing factories have also, perhaps, contributed indirectly to the general increase in the cotton acreage.

We may now examine the coefficients of variability of acreage under cotton for the various districts. Khandesh shows the least variability of 8 per cent, Dharwar coming next with 13 per cent; others have a variability of 15 to 30 per cent, excepting Ahmednagar which has a coefficient of variability as high as 55 per cent.

As, however, in taking data of prices for correlation with acreages, the varietal prices of the season and crop reports have been used, the acreage series for the districts have to be reduced to the same period, *i.e.*, 1899-1900 to 1931-32, for a comparative study. Table 5 gives the values of $\varkappa$'s for this shorter period for each of the districts. It is seen that the figures indicate conspicuous straight line trends similar to those shown by the longer series referred to in Table 4.

The four series of cotton prices given in table 3 are also treated by curve fitting in a similar way and the results are given in the form of $\varkappa$'s with their standard residues in Table 6.

TABLE 6

Secular changes in Prices.

	Bombay Broach (1889-1931)	Bombay Broach (1899-1931)	Broach variety (1899-1931)	Khandesh variety (1899-1931)	Dharwar variety (1899-1931)
Mean . .	1·47	1·35	1·30	1·64	1·35
S. D. . .	0·473	0·469	0·425	0·539	0·460
$\varkappa'_2$ . . .	−2·07	−1·59	−1·36	−1·64	−1·53
$\varkappa'_3$ . . .	+0·35	+1·38	+1·18	+1·07	+1·32
$\varkappa'_4$ . . .	+1·63	+0·71	+0·80	+1·06	+0·72
Standard residue	0·246	0·268	0·255	0·387	0·273

It is seen from the values of $\varkappa'_2$s for all the series that there has been a significant decrease in the value of cotton prices during the period concerned. As the unit of the series is "Seers per Rupee", this trend would mean that the price of cotton has been increasing during the period under consideration. Secular changes of higher order have also taken place and they are shown in Fig. 5 where the polynomials are plotted.

It is also interesting to note how far the prices of cotton given by the "Bombay Broach" quotations are correlated with the three varietal prices given in the Season and Crop Reports. The correlation coefficients, after eliminating trend, of the Bombay Broach prices with the other three prices are as follows:—

Khandesh variety	+·83
Dharwar variety	+·96
Broach variety	+·94

The Dharwar and Broach variety prices show slightly higher correlation with the Bombay Broach prices than with the Khandesh variety. The fact that Dharwar and Broach varieties of cotton are long stapled whereas the Khandesh is short stapled may be noted here.

Correlation of prices with acreages in the different districts after allowing for the secular changes are given in Table 7. Columns 2 and 3 give the values of correlation of " Bombay Broach " prices for a period of 43 and 33 years, respectively, and column 4 gives the correlation coefficients with acreages using varietal prices over a corresponding period of 33 years.

TABLE 7

Correlation of Acreage with Price and Rainfall

Districts	Bombay Prices 43 years	Bombay Prices 33 years	Varietal Prices 33 years	Rainfall 33 years				
				May	June	July	August	September
Ahmedabad	−·488	−·516	−·488	..	+·150	+·169	−·065	..
Broach	−·569	−·717	−·639	..	−·236	−·134	−·094	..
Surat	−·609	−·699	−·781	..	−·088	−·575	−·043	..
Khandesh	−·254	−·393	−·461	+·240	+·088	+·054	..	..
Ahmednagar	+·063	−·037	−·103	..	+·672	+·143	..	..
Belgaum	−·196	−·190	−·267	..	−·217	+·412	+·354	+·139
Bijapur	−·275	−·237	−·304	..	+·056	−·018	+·487	+·108
Dharwar	−·382	−·488	−·491	..	+·053	+·106	+·152	+·235

The varietal prices were used as follows:—

For District	Varietal price used
Ahmedabad, Broach, Surat	" Broach."
Khandesh, Ahmednagar	" Khandesh ".
Belgaum, Bijapur, Dharwar	" Dharwar ".

The cotton acreage in the Ahmednagar district seems to be independent of prices and although the correlations for Belgaum and Bijapur are high, they do not reach the 5 per cent level of significance. Other districts, however, show significant correlations with prices. In all districts of the Deccan and Karnatak divisions, the varietal prices seem to govern acreages slightly better than the Bombay prices. The varietal prices were therefore taken in determining the regression of prices on acreages.

5. *Acreage-rainfall correlations.*—The weather factor studied in this paper in relation to the fluctuations in cotton acreage is rainfall of the sowing season. The monthly rainfall data are obtained from the records of the provincial raingauge stations. The mean rainfall of a district for a particular month was taken to represent the average rainfall conditions over the whole district. The series of these monthly rainfalls for all the districts for 33 years were subjected to analysis by fitting orthogonal polynomials of 3rd degree as in the case of acreage and price series. The results of this analysis together with the mean and the standard deviations in each case are given in Table 8.

TABLE 8

Secular changes in the monthly rainfalls (33 years 1899—1931)

	May	June	July	August	September
Ahmedabad—					
Mean		3·24	10·52	7·18	
S. D.		2·72	7·51	4·98	
χ'_2		+0·76	+8·83	+0·82	
χ'_3		−5·63	−1·55	+1·25	
χ'_4		+1·21	+9·00	+8·03	
S. R.		2·65	7·52	5·01	
Surat—					
Mean		8·62	22·98	13·55	
S. D.		6·68	10·19	6·96	
χ'_2		+0·90	+13·56	−1·00	
χ'_3		−8·78	+1·75	+0·64	
χ'_4		+1·18	+18·96	+1·43	
S. R.		6·82	9·79	7·30	
Broach—					
Mean		5·56	11·87	6·71	
S. D.		5·03	5·67	4·50	
χ'_2		+4·76	+6·21	−2·79	
χ'_3		−6·38	+4·87	+1·81	
χ'_4		+3·91	+17·07	+1·80	
S. R.		5·02	4·82	4·67	
Khandesh—					
Mean	0·39	5·12	8·36	..	
S. D.	0·59	2·51	2·82	..	
χ'_2	−0·34	+2·09	+2·76	..	
χ'_3	−0·38	−4·62	−0·95	..	
χ'_4	−0·60	+2·51	+5·91	..	
S. R.	0·60	2·42	2·70	..	
Ahmednagar—					
Mean	..	4·44	3·56	..	
S. D.	..	1·94	2·34	..	
χ'_2	..	+1·97	−0·95	..	
χ'_3	..	+0·16	−2·59	..	
χ'_4	..	+2·58	+1·94	..	
S. R.	..	1·95	2·38	..	
Belgaum—					
Mean		6·24	11·54	6·76	4·75
S. D.		1·91	5·14	3·84	2·10
χ'_2		−2·87	+3·17	−0·59	+0·87
χ'_3		+2·00	−1·86	−2·25	−0·56
χ'_4		−0·75	+1·57	+3·99	+1·74
S. R.		1·89	5·35	3·94	2·17

TABLE 8—*contd*

	May	June	July	August	September
Bijapur—					
Mean		2·82	2·64	2·37	6·29
S. D.		1·15	1·97	2·11	2·86
x'_2		−0·38	−0·79	−3·97	+2·72
x'_3		+2·98	−4·29	−3·67	+2·65
x'_4		+0·95	+1·69	+3·56	+1·57
S. R.		1·05	1·88	1·86	2·91
Dharwar—					
Mean		3·48	5·09	3·42	4·15
S. D.		1·13	2·28	1·75	1·83
x'_3		−0·91	+1·34	−0·69	+1·63
x'_2		+1·87	−4·25	−2·08	+1·09
x'_4		+0·40	+0·94	3·15	+0·38
S. R.		1·12	2·24	1·69	1·89

There are indications of secular changes in (1) rainfall of Bijapur district for the months of June, July and August, (2) July rainfall of Broach district, and (3) September rainfall of Ahmednagar district. It is beyond the scope of this paper to investigate in detail the nature and causes of these secular changes.

The correlation coefficient between cotton acreages and monthly rainfall of each month during the sowing season for various districts are given in columns 4 to 7 of Table 7. Out of these correlation coefficients, only the following are found to be significant : June rainfall in Ahmadnagar, July and August rainfall in Belgaum district, and August rainfall in Bijapur District. In all these cases the rainfall shows a positive correlation with the acreage. In one case, *viz.*, Surat district, July rainfall shows a significant negative correlation with acreage.

From an examination of Table 7 the varaietes to be used for the regression formula for various districts to calculate the cotton acreages from the prices and weather conditions were chosen as follows. Though some of these factors have not given significant correlations they have been included as the values were fairly high.

District	Factors used	
	Prices	Rainfall
Ahmedabad	p	
Broach	p	June rainfall.
Surat	p	July rainfall.
Khandesh	p	May rainfall.
Ahmadnagar	..	June rainfall.
Belgaum	p	July and August rainfall.
Bijapur	p	August rainfall.
Dharwar	p	September rainfall.

The regression formulæ expressing acreages in terms of the chosen factors are given in Table 9 with the values of t's for the respective regression coefficients and of R the multiple correlation coefficient.

TABLE 9

District	Regression equation	Rainfall	Value of		R
			t_p	t_r	
Ahmedabad .	$A = -202 \cdot 00\ P$	..	2·96	..	·488
Broach . .	$A = -91 \cdot 79\ P - 1 \cdot 55\ r$	June	4·42	1·47	·672
Surat . .	$A = -55 \cdot 36\ P - 0 \cdot 92\ r$	July	8·01	5·11	·895
Khandesh .	$A = -113 \cdot 49\ P + 33 \cdot 47\ r$	May	2·66	1·22	·504
Ahmednagar .	$A = +23 \cdot 69\ r$	June	..	4·81	·672
Belgaum . .	$A = -52 \cdot 78\ P + 3 \cdot 34\ r_1 + 2 \cdot 20\ r_2$	July August	1·70	1·86 0·91	·531
Bijapur . .	$A = -144 \cdot 51\ P + 38 \cdot 15\ r$	August	1·58	2·84	·549
Dharwar . .	$A = -136 \cdot 88\ P + 11 \cdot 52\ r$	September	3·39	1·98	·581

Table 10 gives the above results in the form of "Analysis of variance". The total sum of squares of deviations of the acreage series for each district is divided into (1) the sum of squares ascribable to the secular changes, (2) the sum of squares ascribable to the influence of prices and rainfall on the series and (3) the residual. Each of these is divided by the appropriate number of degrees of freedom to give the corresponding mean square. The mean square against "total" can be compared with the mean square against "residual", the reduction indicating the extent of variation that has been accounted for by the secular changes and the regression equation. It is seen that in all cases the reduction amounts to a fairly good portion of the total variation.

Finally the values of acreages as given by the Regression Equations in Table 9 are calculated and these are added to the polynomial values of the series. These values which are called "Calculated Values" are plotted with the actual values and the polynomial curve for each series in Figs. 6-*a* and 6-*b* for comparison.

TABLE 10

Analysis of Variance

District	Due to	D. F.	Mean sq.	S. D.
Ahmedabad .	Total	32	20120	142
	Polynomial	3	106715	
	Deviations from Polynomial .	29	11762	106
	Regression	1	77094	
	Residual	28	8807	94

TABLE 10—*contd.*

District	Due to	D. F.	Mean sq.	S. D.
Broach	Total	32	2786	53
	Polynomial	3	16376	
	Deviations from Polynomial	29	1381	36
	Regression (Prices and June rain)	2	9048	
	Residual	27	812	28
Surat	Total	32	1200	35
	Polynomial	3	8855	
	Deviations from Polynomial	29	408	20
	Regression (Prices and July rain)	2	4748	
	Residual	27	87	9
Khandesh	Total	32	16870	130
	Polynomial	3	85652	
	Deviations from Polynomial	29	9755	99
	Regression (Prices and May rain)	2	35921	
	Residual	27	7816	88
Ahmednagar	Total	32	5220	72
	Polynomial	3	9964	
	Deviations from Polynomial	29	4729	69
	Regression (June rain)	1	61949	
	Residual	28	2685	52
Belgaum	Total	32	3849	61
	Polynomial	3	16369	
	Deviations from Polynomial	29	2554	51
	Regression (Prices July and August rain)	3	6975	
	Residual	26	2044	44
Bijapur	Total	32	33101	182
	Polynomial	3	123012	
	Deviations from Polynomial	29	23800	154
	Regression (Prices and August rain)	2	104094	
	Residual	27	17582	133
Dharwar	Total	32	8480	91
	Polynomial	3	43559	
	Deviations from Polynomial	29	4852	70
	Regression (Prices and September rain)	2	23726	
	Residual	27	3454	59

Summary and Conclusion.—The acreage under cotton over the period under consideration shows a tendency to increase, mostly due to the high prices of cotton ; but, of late, certain districts show a decreasing tendency in the cotton acreage due to fall of prices of cotton.

The coefficient of variability of cotton acreage is the least, being 8 per cent for Khandesh ; Dharwar comes next with 13 per cent. Others have a variability of 15 to 30 per cent. except Ahmednagar for which the variability is the highest, being 55 per cent.

Acreage under cotton in the Ahmednagar district shows significant positive correlation with June rainfall, while prices do not seem to affect the acreage under cotton in this district. July and August rainfall in Belgaum and August rainfall in Bijapur show a significant positive correlation with cotton acreage. The cotton acreages in these districts, as in the case of Ahmednagar, do not seem to be significantly influenced by prices. Cotton acreage in the Surat district shows a significant negative correlation with July rains. High prices of cotton, are seen to increase the cotton acreage significantly in the districts of Ahmedabad, Broach, Surat, Khandesh and Dharwar districts.

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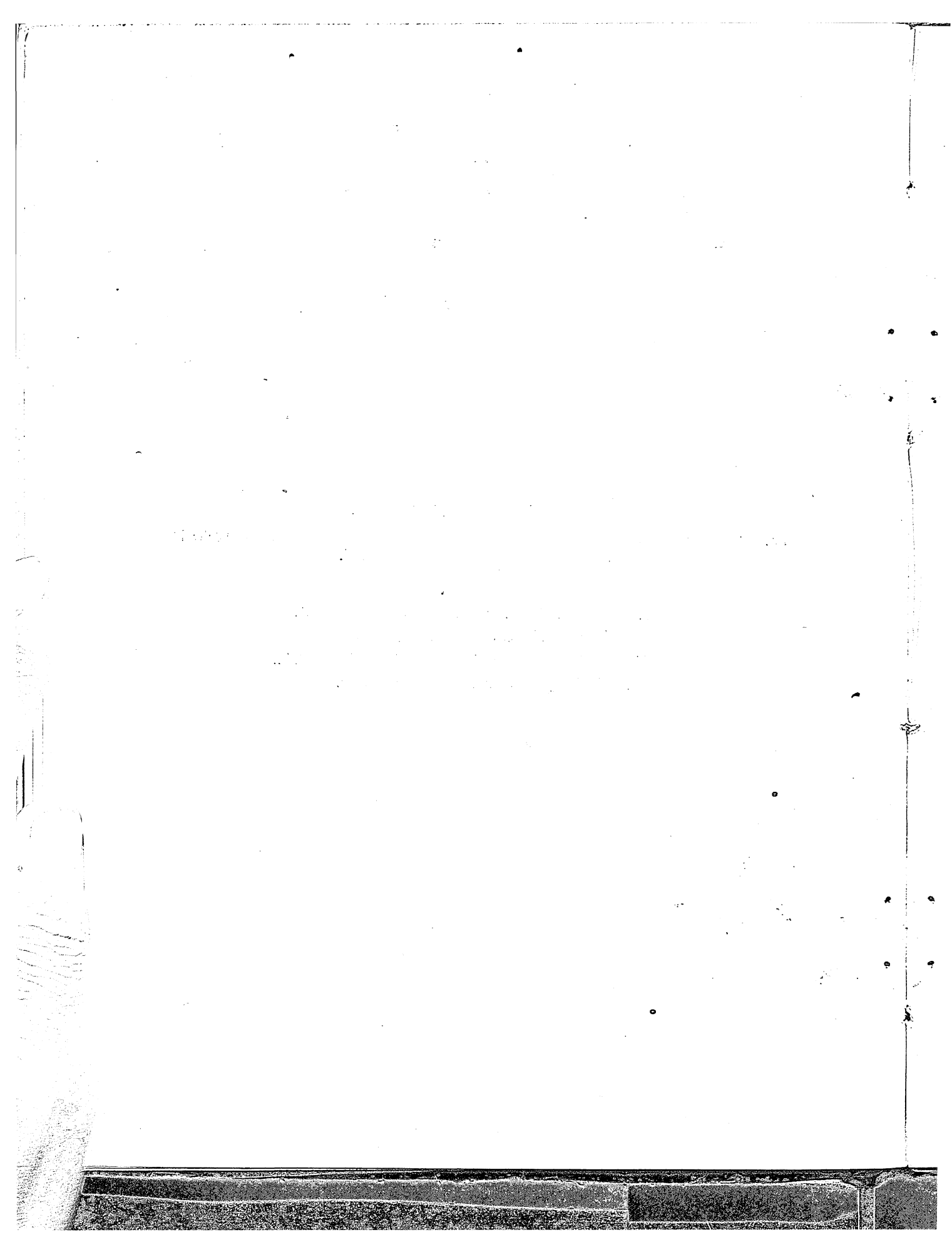
AGRICULTURAL METEOROLOGY.

IV.—"INFLUENCE OF WEATHER ON THE YIELD PER ACRE OF COTTON IN THE BOMBAY PRESIDENCY".

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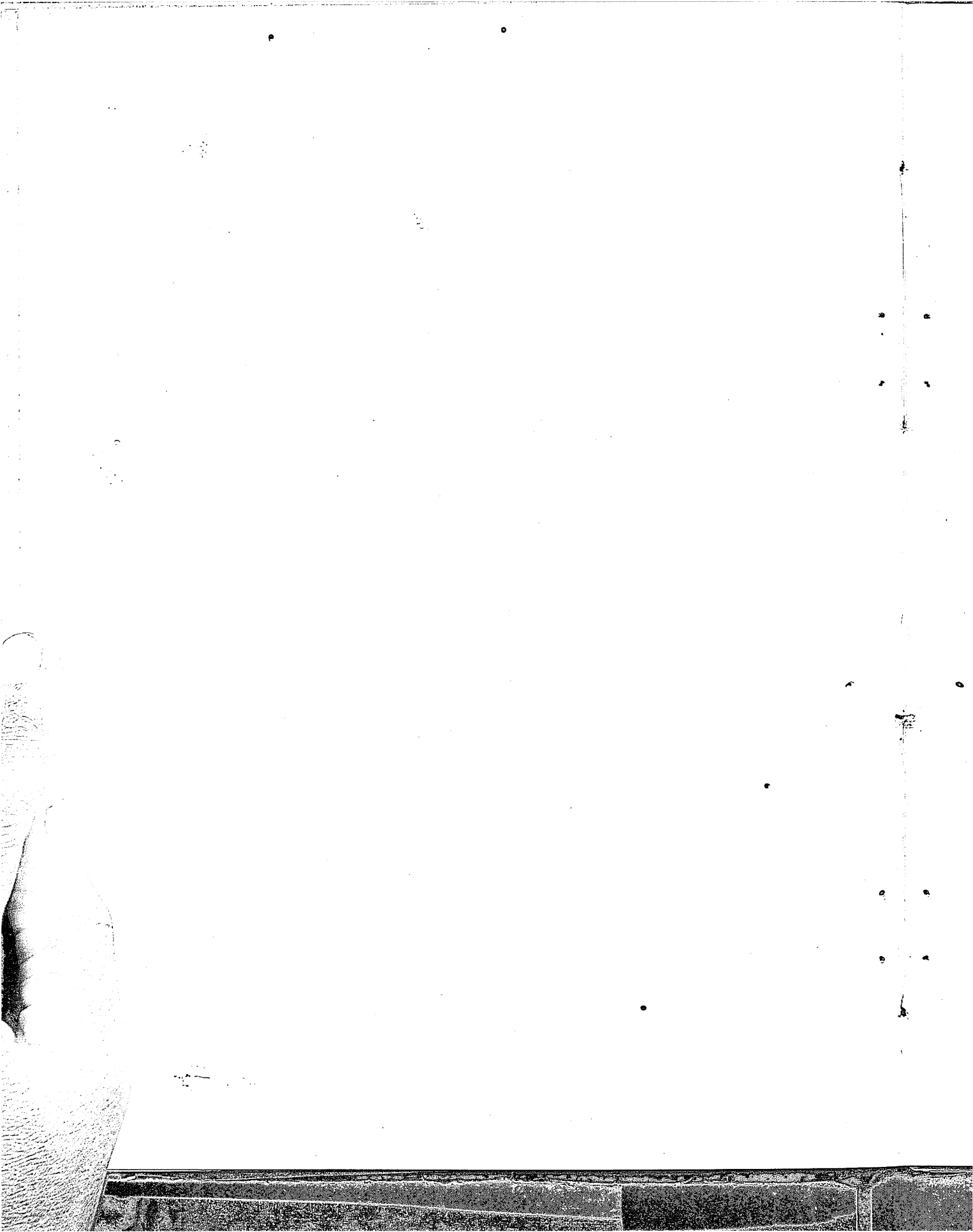
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ABSTRACT.

The influence of rainfall and maximum temperature on the yield of cotton for 8 districts of the Bombay Presidency is investigated in this paper. The data extend over a period of 43 years commencing from 1889-90. It is observed that the Ahmednagar and the Bijapur districts are most subject to the vagaries of weather, the coefficient of variability of yield for these districts being of the order of 42 per cent. ; the coefficient of variability for Surat is the lowest, being 23 per cent.

The yearly fluctuations in the yield per acre of cotton in the cotton growing districts of the Bombay Presidency, on the whole, seem to be significantly influenced by the rainfall as well as the maximum temperature prevalent in the growing season. Rainfall gives a positive correlation with yield. High maximum temperature of May in Khandesh and Surat districts show a significant beneficial effect on yield which may be attributable to the fact that, under the influence of the hot sun, the black cotton soil " ploughs itself " and thus exercises a beneficial effect on the subsequent crop of cotton grown on it. Such beneficial effect of mean maximum temperature for the month of May is also indicated in the case of the Ahmadabad district. On the other hand, maximum temperature above the normal shows an adverse effect on the yield during the flowering and bolling period of cotton.



AGRICULTURAL METEOROLOGY.

"INFLUENCE OF WEATHER ON THE YIELD PER ACRE OF COTTON IN THE BOMBAY PRESIDENCY"*

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1. *Introduction.*—The total out-turn of a crop depends on the area and the yield per acre of the crop for the season. The success or failure of a forecast of the out-turn will depend on the accuracy of the estimates of these elements. In India the system of collecting Land Revenue fortunately affords us fairly accurate statistics of area sown to different crops in most provinces[1]. The variations of this element from season to season for the cotton crop in the Bombay Presidency have been discussed in another paper[2].

The aim of this paper is to study the fluctuations of the second element *viz.* the "yield per acre" of the cotton crop in the districts of the Bombay Presidency in relation to the weather conditions prevailing during different years.

2. *Yield statistics and their limitations.*—At the outset it is necessary to note the nature of yield statistics available in India, in general, and their limitations. The yield per acre figures for crops are not available directly from the official statistics but they can be computed from two factors *viz.* (1) "the standard out-turn" and (2) "the condition estimate"[3]. The first represents the average yield that can be expected over a certain area (*e.g.* a district) from a normal crop. Various definitions of the word "normal" have been put forward at different times and places. Briefly, it is "the average yield on average soil in a year of average character". It is the lack of exactitude of this definition that limits the accuracy of this measure[4]. The standard out-turn which is also called the "normal yield" is arrived at from a series of "crop cutting experiments" and the figures are reviewed ordinarily once in 5 years and revised if necessary. These figures are available in the quinquennial publication of the Department of Commercial Intelligence and Statistics entitled "Average yield per acre of principal crops in India".

The second factor which is also called "seasonal factor" or "anna value" or "condition factor" for each district is said to denote the ratio of the season's crop to the normal crop. Usually, the cultivators estimate the crop out-turn in annas. They take a certain number of annas to represent the normal out-turn and estimate the out-turn of the year of report as so many annas higher or lower than the normal. There is, however, no fixity in the standard of anna notation, and the number of annas taken to represent a normal out-turn varies between 12 and 16. This estimate is essentially a visual one and has come in for much criticism [1, 4, 5] for lack of exactitude. But the fact that the district condition figure is the average of the condition factors of a large number of villages for each of which an estimation is made separately tends to decrease the error in the mean value of this factor for the district to the extent that over-estimates in some villages may be expected to compensate under-estimates in others in each year. It may be expected that the available data of "yield per acre" would give some indication of the influence of

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weather on crops. How far these hopes are realised in the case of the cotton crop in the Bombay Presidency will be seen in the following sections.

TABLE 1.

Condition factor of cotton expressed as percentage of normal yield per acre.

Years.	Ahmad-abad.	Broach.	Surat.	Khan-dosh.	Ahmad-nagar.	Bel-gaum.	Bijapur.	Dhar-war.
1889–1890 . .	69	106	63	94	75	75	69	44
91 . .	44	63	56	88	63	50	44	44
92 . .	56	100	81	81	38	31	13	19
93 . .	56	106	56	56	44	81	63	82
94 . .	63	50	50	69	56	56	63	56
95 . .	63	50	44	63	31	50	50	56
96 . .	69	81	63	81	56	75	44	44
97 . .	56	56	63	44	44	38	2	44
98 . .	92	75	83	100	25	42	33	50
99 . .	83	75	58	92	75	75	50	50
1899–1900 . .	8	33	42	25	10	25	13	50
01 . .	33	75	92	108	42	42	17	50
02 . .	25	42	58	67	50	42	33	83
03 . .	83	83	92	92	58	50	33	67
04 . .	92	92	100	75	58	92	83	100
05 . .	50	42	58	67	33	42	42	67
06 . .	75	83	75	83	33	42	8	33
07 . .	75	92	92	72	58	67	67	92
08 . .	33	67	92	48	42	67	67	92
09 . .	50	67	75	64	33	58	58	50
1909–1910 . .	99	103	103	94	85	83	81	83
11 . .	64	76	74	92	43	85	85	69
12 . .	25	50	58	57	21	44	51	34
13 . .	85	100	103	64	3	75	58	100
14 . .	93	92	89	96	80	67	57	75
15 . .	74	100	65	83	99	83	76	83
16 . .	41	58	69	125	86	78	88	83
17 . .	86	92	83	97	73	70	82	83
18 . .	59	75	83	67	64	85	75	92
19 . .	34	39	67	46	27	57	57	58
1919–1920 . .	92	92	78	120	64	75	67	75
21 . .	42	42	72	40	3	58	50	58
22 . .	67	67	58	95	58	75	67	67
23 . .	83	82	85	83	75	67	33	58
24 . .	42	69	48	80	67	58	50	75
25 . .	100	103	88	76	75	75	50	75
26 . .	50	71	68	61	67	83	42	75
27 . .	50	72	54	72	58	50	50	50
28 . .	67	73	72	78	75	67	75	67
29 . .	33	43	33	77	67	75	92	75
1929–1930 . .	42	64	70	67	33	67	58	67
31 . .	50	70	80	85	58	50	42	50
32 . .	75	58	77	53	58	58	58	58
Mean . .	61·1	72·8	71·4	76·2	52·6	62·4	53·4	64·7
Standard Deviation.	22·6	20·4	16·9	20·7	22·4	16·6	22·1	18·9
Coefficient of variation.	37·0	28·1	23·7	27·1	42·5	26·5	41·3	29·2

3. *Analysis of "Seasonal Factor".*—In Table 1 are given the percentage out-turns of cotton computed from the condition factor for the 8 cotton growing districts of the Bombay Presidency for a period of 43 years beginning with the season of 1889-90, together with their standard deviations and coefficients of variability. If the condition factors reported for a district over a fairly long series of years correctly represent the condition of the crop in those years as proportions of the normal crop, then the average of these should not differ appreciably from 100 which represents the normal condition of the crop. It is interesting, however, to note that in no case does the mean approach this normal value of 100, indicating a tendency on the part of the estimator to under-value the condition of the crop generally. The detailed examination in recent years of the official forecasts, the returns of cotton ginned and pressed, and trade statistics by the Indian Central Cotton Committee has also shown that the yield of cotton has in general been under estimated[6].

In the Bombay Presidency, the Bijapur and Ahmednagar districts have the lowest mean percentage out-turns with the highest variability of about 42 per cent. Khandesh district has the highest mean percentage out-turn with a variability of 27 per cent. The percentage out-turn of the Surat district has the lowest variability of 24 per cent. An analysis of variance of the figures of table 1 shows the following interesting features :—

Factor.	D. F.	Sum of square.	Mean square.
Between districts	7	22,910	3,272·85
Between years	42	63,418	1,509·95
Within years	294	73,561	250·21
Total .	343	1,59,889	466·15

The variation between districts is highly significant showing that the tendency to under-estimate the condition factor varies from district to district. The variation between years also is significant and shows that the effect of seasons is significantly reflected in the estimates. Owing to the limitations of the data, however, as previously observed, it cannot be expected that the statistical analysis of the "yield per acre" and weather factors would indicate anything more than certain general relationships.

4. *"Yield per acre" data.*—The yield per acre of cotton for each year for each district is obtained by multiplying the standard yield by the condition factor of the crop for the year. It may be noted that the normal yield was equivalent to a 16 anna crop upto the year 1896-97 and to a 12 anna crop thereafter for the purpose of estimating the condition factor. The condition factor is given in the reports in the form of percentage of the normal yield from 1905-06 onwards. The yield of cotton in lbs. per acre for the various districts computed as above are given in Table 2.

TABLE 2.

Cotton yields in lbs. of lint per acre.

Years.	Ahmed-abad.	Broach.	Khan-desh.	Ahmad-nagar.	Bel-gaum.	Bijapur.	Dhar-war.	Surat.
1889-1890	83·9	134·9	90·0	72·0	72·0	66·0	42·0	80·6
91	53·4	79·4	84·0	60·0	48·0	42·0	42·0	72·6
92	68·6	127·0	78·0	36·0	30·0	12·0	18·0	104·8
93	68·6	134·9	54·0	42·0	78·0	60·0	78·0	72·6
94	76·3	63·5	66·0	54·0	54·0	60·0	54·0	64·5
95	76·3	63·5	60·0	30·0	48·0	48·0	54·0	56·4
96	83·9	103·2	78·0	54·0	72·0	42·0	42·0	80·6
97	68·6	71·4	42·0	42·0	36·0	2·3	42·0	80·6
98	114·6	97·5	90·0	22·5	42·0	30·0	50·0	100·0
99	104·2	97·5	82·5	67·5	75·0	45·0	50·0	70·0
1899-1900	10·4	43·3	22·5	9·1	25·0	11·8	50·0	50·0
01	41·7	97·5	97·5	37·5	42·0	15·0	50·0	110·0
02	31·3	54·2	60·0	45·0	42·0	30·0	83·3	70·0
03	104·2	108·3	82·5	52·5	50·0	30·0	66·6	110·0
04	114·6	119·2	67·5	52·5	92·0	75·0	100·0	120·0
05	62·5	54·2	60·0	30·0	42·0	37·5	66·6	70·0
06	93·8	107·9	74·7	29·7	42·0	7·2	33·0	90·0
07	93·8	119·6	64·8	52·2	67·0	60·3	92·0	110·4
08	41·3	87·1	43·2	37·8	67·0	60·3	92·0	110·4
09	62·5	87·1	57·6	29·7	58·0	52·2	50·0	90·0
1909-1910	123·8	133·9	84·6	76·5	83·0	72·9	83·0	123·6
11	80·0	98·8	82·8	38·7	85·0	76·5	69·0	88·8
12	31·3	65·0	51·3	18·9	44·0	45·9	34·0	69·6
13	106·3	130·0	57·6	3·8	75·0	52·2	100·0	123·6
14	116·3	119·6	86·4	72·0	67·0	51·3	75·0	106·8
15	92·5	130·0	74·7	89·1	83·0	68·4	83·0	78·0
16	51·3	75·4	112·5	77·4	78·0	79·2	83·0	82·8
17	107·5	119·6	87·3	65·7	70·0	73·8	83·0	99·6
18	73·8	97·5	73·7	57·6	85·0	67·5	110·4	99·6
19	42·5	51·0	50·6	24·3	57·0	51·3	69·6	80·4
1919-1920	115·0	119·6	132·0	57·6	75·0	60·3	90·0	93·6
21	52·5	54·6	44·0	2·7	58·0	45·0	69·6	86·4
22	83·8	87·1	104·5	52·2	75·0	60·3	80·4	69·6
23	103·8	106·6	91·3	67·5	67·0	29·7	69·6	102·0
24	52·5	89·7	88·0	60·3	58·0	45·0	90·0	57·6
25	125·0	133·9	83·6	67·5	75·0	45·0	90·0	105·6
26	62·5	92·3	67·1	60·3	83·0	37·8	90·0	81·6
27	62·5	93·6	79·2	52·2	50·0	45·0	60·0	64·8
28	83·8	94·9	85·8	67·5	67·0	67·5	80·4	86·4
29	41·3	55·9	84·7	60·3	75·0	82·8	90·0	39·6
1929-1930	52·5	83·2	73·7	29·7	67·0	52·2	80·4	84·0
31	62·5	91·0	93·5	52·2	50·0	37·8	60·0	96·0
32	93·8	75·4	..	52·2	58·0	52·2	69·6	92·4
Mean	76·1	94·2	74·9	48·0	62·0	48·5	69·0	86·6

An inspection of table 2 indicates that some progressive slow changes have occurred in the "yield per acre" during the period under investigation. These slow changes may be due to the influence of such counteracting factors as high prices, intensive cultivation, land under the margin of cultivation being brought under the plough, introduction of improved varieties, improvement or otherwise in the accuracy of estimation etc. As our aim is to correlate the data with the

weather factors of individual years it is necessary to obtain the variations in the yield per acre after eliminating these progressive or slow changes. This is done as usual by fitting a polynomial curve[7] to the series of data. The values of x′s for all the series with means, standard deviations (S. D.) and standard residues (S. R.) are given in table 3. All the districts except Ahmedabad, Broach and Ahmadnagar show slow changes. These secular variations will be referred to again while discussing the results for each district.

TABLE 3.

	Ahmad-abad.	Broach.	Surat.	Khan-desh.	Ahmad-nagar.	Bel-gaum.	Bijapur.	Dhar-war.
Mean yield .	76·1	94·2	86·6	74·9	48·0	62·0	48·5	69·0
Standard Deviation (S. D.).	28·2	26·4	19·8	20·5	20·2	16·6	19·9	21·2
Coefficient of variability.	37·1	28·0	22·8	27·4	42·1	26·8	41·1	30·7
x'_2 . .	+3·90	—13·76	+3·17	+35·35	+22·22	+35·54	+39·40	+74·14
x'_3 . .	—25·02	—11·28	—44·06	+19·84	+17·02	—19·02	—13·83	—42·25
x'_4 . .	—13·95	—46·88	+6·84	—28·20	—32·19	—32·75	—37·16	—12·70
x'_5 . .	+8·63	+36·91	..	..	..	..	+42·60	..
S. R. . .	29·3	25·8	19·3	19·7	19·8	15·1	17·6	17·1
No. of years .	43	43	43	42	43	43	43	43

5. *Meteorological Factors.*—Large fluctuations in the yield per acre of cotton may be expected as a result of the fluctuations of weather from year to year during the growing season of the crops. Rainfall and temperature are two of the prominent weather factors affecting the cotton crop. Our past information regarding these elements consists of:

(*i*) the daily rainfall recorded at a number of rain-gauge stations in each district (about 10 usually per district) and

(*ii*) the temperature recorded daily at the meteorological observatories of the India Meteorological Department (usually one in each district).

One may expect that the mean district rainfall obtained by averaging the data of all the raingauge stations in the district would provide a satisfactory index of the rainfall conditions over the area. The temperature recording stations are, however, few in number, there being usually not more than one station to represent the varying conditions over a large tract like the district. In this connection it may be mentioned that studies at Poona on the microclimates [8], [9] of crops show that the temperature, humidity, etc., measured in an open space differ from those recorded simultaneously in the actual environment of a crop. While the conditions in the open and inside a crop are highly correlated at the epoch of minimum temperature, this is not so at the epoch of maximum temperature. The above difficulty is serious particularly in the case of the tall crops. We see therefore that past records of the "macro" or general weather factors also may have inherent shortcomings.

In view of these limitations of the data, only the effects of monthly values of weather factors have been considered in relation to the yields although it is realised

that the distribution* of these weather factors during the growing season of the crop exerts a considerable influence on the ultimate yield. The average monthly rainfalls over the various districts of the Bombay Presidency are given in Table 4 with their standard deviations (S. D.). The monthly mean maximum temperatures with their standard errors for the various districts are given in Table 5. For the Khandesh district where there was no observatory the average of the temperatures recorded at Akola, Malegaon and Khandwa was taken.

For those districts where the yield data were found to indicate secular changes, the monthly rainfall and maximum temperature series have also been subjected to polynomial fitting of the same degree and the resulting values of x′s are also given in Tables 4 and 5, for rainfall and temperature respectively. The monthly rainfall and temperature series used are given in Appendices A and B.

TABLE 4.

Secular changes in the Monthly Rainfall (in inches).

—	June.	July.	August.	September.	October.	November.
Ahmadabad.						
Mean	3·8	11·1	7·1	2·7	..	..
Standard Deviation (S. D.)	3·1	7·5	4·8	3·1	..	..
Broach.						
Mean	6·3	13·0	6·8	5·0	1·2	..
Standard Deviation (S. D.)	5·3	6·7	4·1	3·9	2·6	..
Surat.						
Mean	9·3	23·9	13·2	8·0	..	..
Standard Deviation (S. D.)	7·2	10·1	6·5	5·6	..	..
x'_2	—5·68	+0·75	+2·76	—0·85	..	..
x'_3	+0·74	+16·05	—3·62	+3·81	..	..
x'_4	—7·33	+2·67	+3·97	—8·63	..	..
Standard Residue (S. R.)	7·4	10·2	6·7	5·6	..	..
Khandesh.						
Mean	5·2	8·4	5·7	5·4	1·2	..
Standard Deviation (S. D.)	2·4	2·9	2·4	3·4	1·5	..
x'_2	+1·60	—0·14	—1·82	—0·64	+0·48	..
x'_3	+0·31	—0·89	+0·33	+3·58	+0·39	..
x'_4	—2·81	+0·73	—1·24	+0·96	—1·53	..
Standard Residue (S. R.)	2·5	3·0	2·5	3·5	1·6	..
Ahmadnagar.						
Mean	4·5	3·6	2·4	6·1	2·5	..
Standard Deviation (S. D.)	2·1	2·2	1·6	3·5	2·1	..
Belgaum.						
Mean	6·5	11·4	6·7	4·7	4·3	1·5
Standard Deviation (S. D.)	2·1	4·8	3·5	2·3	2·4	2·0
x'_2	—4·03	+3·41	+0·27	+1·03	—4·18	+2·28
x'_3	—0·09	—0·36	—2·39	—0·03	+3·22	—0·46
x'_4	+3·02	—0·32	+1·19	—0·17	—0·75	—4·41
Standard Residue (S. R.)	2·0	5·0	3·6	2·4	2·3	1·9

* Yield data from Government Experimental farms are the result of actual measurements and not estimates like the district figures discussed here. The former are more reliable and, where the data extend over a long series of years, it would be well worth-while to study the effect of distribution of weather factors in greater detail.

TABLE 4—*contd.*

	June.	July.	August.	September.	October.	November.
			Bijapur.			
Mean . . .	3·0	2·6	2·5	6·4	3·3	1·4
Standard Deviation (S. D.) .	1·2	1·8	2·1	2·9	2·5	1·9
x'_2 . . .	—1·60	—0·35	—4·00	+0·70	—4·48	+1·25
x'_3 . . .	+2·34	—2·68	—2·93	+3·74	+5·24	+0·09
x'_4 . . .	+2·09	—2·36	—1·15	+1·65	—3·22	—3·26
x'_5 . . .	+0·69	+2·17	+2·36	+2·42	+2·26	—0·01
Standard Residue (S. R.) .	1·1	1·8	2·0	2·9	2·3	1·9
			Dharwar.			
Mean . . .	3·7	5·0	3·5	4·3	4·2	1·6
Standard Deviation (S. D.) .	1·2	2·1	1·8	2·3	2·1	2·0
x'_2 . . .	—2·04	+2·12	—0·83	+0·19	—4·25	+1·75
x'_3 . . .	+0·67	—2·41	—1·45	+2·29	+1·57	+0·77
x'_4 . . .	+2·83	—2·43	+0·45	—0·36	—1·09	—3·64
Standard Residue (S. R.) .	1·2	2·0	1·8	2·3	2·0	2·0

TABLE 5.

Secular changes in the mean monthly maximum temperature. (*in °F.*)

	May.	June.	July.	August.	September.	October.	November.	December.
Ahmedabad—								
(1893-94 to 1931-32)—								
Mean . .	107·3	101·8	93·1	89·9	92·5	97·0	92·4	86·2
S. D. . .	2·1	3·3	3·6	2·8	3·1	3·1	2·6	2·0
Surat—								
(1889-90 to 1931-32)—								
Mean . .	97·3	93·0	87·4	86·3	88·6	94·0	92·0	
S. D. . .	1·8	2·1	1·8	1·5	2·0	2·8	2·6	
x'_2 . .	—3·66	—2·69	—2·46	—4·05	—1·46	—0·46	—1·49	
x'_3 . .	+3·79	+2·65	—1·62	+1·25	—0·04	—6·13	—5·11	
x'_4 . .	—2·24	+3·34	+0·94	—0·15	+2·04	+4·84	+4·62	
Standard Residue.	1·6	2·0	1·8	1·4	2·0	2·7	2·4	
Khandesh—								
(1889-90 to 1930-31)—								
Mean . .	106·9	98·6	88·9	86·8	89·2	92·7	88·4	
S. D. . .	1·9	3·4	1·8	1·8	2·5	3·3	2·8	
x'_2 . .	+0·62	+3·96	—0·68	+2·78	+2·72	+2·88	—0·73	
x'_3 . .	—1·20	—2·11	—2·92	—1·08	—0·75	—3·40	—4·54	
x'_4 . .	+2·21	+4·15	+0·66	+2·07	+1·33	+4·78	+3·23	
Standard Residue.	1·9	3·4	1·8	1·7	2·5	3·3	2·8	

TABLE 5—*contd.*

	May.	June.	July.	August.	September.	October.	November.	December.
Ahmadnagar—								
(1889-90 to 1931-32)—								
Mean . .	101·6	92·4	85·5	85·0	86·2	88·8		
S. D. . .	3·3	3·1	1·4	1·9	2·2	3·1		
Belgaum—								
(1889-90 to 1931-32)—								
Mean . .	..	..	..	..	79·4	83·4	82·8	82·1
S. D. . .	..	..	..	..	1·4	2·1	2·1	1·7
x'_2 . .	..	..	..	..	+1·12	+0·69	+1·35	+0·72
$1'_3$ . .	..	..	..	..	+0·77	—2·09	+0·31	+1·79
x'_4 . .	..	..	..	..	+1·79	+2·70	+2·84	+0·86
Standard Residue.	..	..	..	..	1·4	2·1	2·1	1·7

6. *Correlations between yields and weather factors.*—The correlation coefficients between the yield per acre series and the monthly rainfall series of June to November and the maximum temperature series for the months of May to December were determined next. In cases where the cotton yield series were observed to indicate secular changes (*i.e.* Surat, Khandesh, Belgaum, Bijapur and Dharwar) the correlation of residuals after eliminating the trend of the required degree was calculated. These coefficients are given in Table 6.

7. *Regression Formulae.*—From the correlation coefficients of Table 6 the weather factors which show fairly high correlations with the yield were chosen to evolve the regression formula for each district. The inter-correlations amongst the chosen weather factors were calculated. It may be observed that the inter-correlations in some cases were very high. The values of correlation coefficients obtained after eliminating the trends were used in the case of districts which showed secular variation of yield. A table of such inter-correlation coefficients was constructed for each district to calculate the regressions of yield on the weather factors chosen [*vide* Tables 7 (*a*) to (*h*)]. The regression equation and the value of the multiple correlation coefficient are given in Table 8 for each district. The significance of the multiple correlation coefficients can be tested by referring to the 5 per cent. and 1 per cent. values of R, (corresponding to available number of degrees of freedom) from Wishart's Tables[7].

The results are also given in Table 9 in the form of an analysis of varience for each yield-per-acre series so as to bring out the amount of variation that has been contributed by the weather factors concerned.

TABLE 6.

Correlation Coefficients of yield with Rainfall and Maximum Temperature.

—	Rainfall.						Maximum Temperature.							
	June.	July.	August.	September.	October.	November.	May.	June.	July.	August.	September.	October.	November.	December.
Ahmadabad	+·121	+·341	+·125	+·383	..	..	+·258	+·017	—·245	—·250	—·481	—·484	—·399	—·442
Broach .	+·039	+·239	+·341	+·321	—·110	..	..	..	..	..	..	..	..	..
Surat .	—·069	+·306	+·322	+·070	..	..	+·320	+·182	+·074	—·314	—·133	—·236	—·206	..
Khandesh .	+·084	+·227	+·162	+·407	+·219	..	+·327	+·144	+·039	—·172	—·457	—·560	—·236	..
Ahmadnagar	+·421	+·170	+·150	+·337	—·045	..	—·104	—·177	—·402	—·124	—·393	—·378	..	..
Belgaum .	+·088	+·141	+·006	+·486	+·404	+·106	..	..	..	..	—·231	—·532	—·442	—·434
Bijapur .	+·335	+·473	+·366	+·508	+·492	+·230	..	..	..	..	..	..	..	..
Dharwar .	+·099	+·243	+·315	+·343	+·231	+·064	..	..	..	..	..	..	..	..

TABLE 7 (*a-h*).

Tables of Correlation coefficients :

Y = yield.

r_1 = June rainfall	t_0 = May	Maximum temperature.
r_2 = July rainfall	t_1 = June	,,
r_3 = August rainfall	t_2 = July	,,
r_4 = September rainfall	t_3 = August	,,
r_5 = October rainfall	t_4 = September	,,
r_6 = November rainfall	t_5 = October	,,
	t_6 = November	,,
	t_7 = December	,,

7-a. Ahmadabad.

Number of years. 39 Factors used r_2, r_4, t_4, t_5, t_6, and t_7.

	r_4	t_4	t_5	t_6	t_7	Y.
r_2	+·0795	—·2624	—·3546	—·4823	—·3769	+·3407
r_4		—·4529	—·4002	—·2466	—·2918	+·3825
t_4			+·6132	+·5095	+·5621	—·4809
t_5				+·6667	+·5184	—·4837
t_6					+·3597	—·3993
t_7						—·4420

7-b. Broach.

Number of years 43. Factors used r_2, r_3 and r_4.

	r_3	r_4	Y.
r_2	+·1152	+·1328	+·2385
r_3		+·2454	+·3406
r_4			+.3207

7-c. Surat.

Number of years 43. Factors used r_2, r_3, t_0, t_3 and t_5.

	r_3	t_0	t_3	t_5	Y.
r_2	+·1713	+·1251	—·4331	—·1941	+·3063
r_3		+·1317	—·4046	—·3244	+·3219
t_0			—·0693	+·1641	+·3205
t_3				+·1440	—·3140
t_5					—·2361

7-d. Khandesh.

Number of years 42. Factors used r_2, r_4, t_0, t_4 t_5 and t_6.

	r_4	t_0	t_4	t_5	t_6	Y.
r_2	+·0532	+·3692	—·2039	—·1301	—·1104	+·2272
r_4		—·0159	—·5827	—·5575	—·4103	+·4074
t_0			+·0233	+·0557	+·0917	+·3266
t_4'				+·7347	+·5255	—·4568
t_5					+·6568	—·5597
t_6						—·2363

7-e. Ahmadnagar.

Number of years 43. Factors used r_1, r_4, t_2, t_4, and t_5.

	r_4	t_2	t_4	t_5	Y.
r_1	—·0239	—·5216	—·2990	—·1156	+·4208
r_4		+·0243	—·5700	—·6797	+·3367
t_2			+·3088	+·0741	—·4018
t_4				+·6871	—·3932
t_5					—·3778

7-f. Belgaum.

Number of years 43. Factors used r_4, r_5, t_5, t_6 and t_7.

	r_5	t_5	t_6	t_7	Y.
r_4	+·2844	—·3392	—·2282	—·1745	+·4855
r_5		—·4841	—·4916	—·3936	+·4038
t_5			+·7133	+·6100	—·5323
t_6				+·6838	—·4421
t_7					—·4338

7-g. Bijapur.

Number of years 43. Factors used r_1, r_2, r_3, r_4, r_5 and r_6.

	r_2	r_3	r_4	r_5	r_6	Y.
r_1	+·0823	+·0601	+·1576	+·3565	+·1720	+·3352
r_2		—·0357	+·0095	+·4682	+·4703	+·4732
r_3			—·0011	+·2303	—·0432	+·3656
r_4				+·0464	+·0741	+·5079
r_5					+·3123	+·4922
r_6						+·2303

7-h. Dharwar.

Number of years 43. Factors used r_2, r_3, r_4 and r_5.

	r_3	r_4	r_5	Y.
r_2	+·4031	—·0662	—·0091	+·2431
r_3		—·0630	—·0602	+·3155
r_4			—·0563	+·3426
r_5				+·2307

TABLE 8.

Regression equations.

1. *Ahmadabad*—

$$Y = +0{\cdot}602\, r_2 + 1{\cdot}760\, r_4 - 1{\cdot}515\, t_4 - 1{\cdot}463\, t_5 - 0{\cdot}505\, t_6 - 2{\cdot}183\, t_7 \quad R = {\cdot}596$$

2. *Broach*—

$$Y = +0{\cdot}699\, r_2 + 1{\cdot}697\, r_3 + 1{\cdot}564\, r_4 \quad R = {\cdot}454$$

3. *Surat*—

$$Y = + {\cdot}271\, r_2 + {\cdot}386\, r_3 + 3{\cdot}668\, t_0 - 2{\cdot}074\, t_3 - 1{\cdot}393\, t_5 \quad R = {\cdot}527$$

4. *Khandesh*—

$$Y = +0{\cdot}217\, r_2 + 0{\cdot}757\, r_4 + 3{\cdot}401\, t_0 - 0{\cdot}379\, t_4 - 3{\cdot}654\, t_5 + 1{\cdot}518\, t_6 \quad R = {\cdot}693$$

5. *Ahmadnagar*—

$$Y = +2{\cdot}644\, r_1 + 1{\cdot}415\, r_4 - 3{\cdot}668\, t_2 + 0{\cdot}346\, t_4 - 1{\cdot}198\, t_5 \quad R = {\cdot}600$$

6. *Belgaum*—

$$Y = +2{\cdot}142\, r_4 + 0{\cdot}739\, r_5 - 1{\cdot}766\, t_5 - 0{\cdot}134\, t_6 - 1{\cdot}484\, t_7 \quad R = {\cdot}649$$

7. *Bijapur*—

$$Y = +2{\cdot}528\, r_1 + 4{\cdot}189\, r_2 + 2{\cdot}897\, r_3 + 2{\cdot}876\, r_4 + 1{\cdot}230\, r_5 - 0{\cdot}621\, r_6 \quad R = {\cdot}825$$

8. *Dharwar*—

$$Y = +1{\cdot}279\, r_2 + 2{\cdot}770\, r_3 + 2{\cdot}852\, r_4 + 2{\cdot}337\, r_5 \quad R = {\cdot}570$$

Y, r and t represent the deviations from the mean in the case of Ahmadabad, Broach and Ahmadnagar districts, and the deviations from the polynomial values for the rest of the districts. The suffixes 0, 1, 2, 3, etc. represent months commencing from May.

TABLE 9.

Analysis of Variance.

	Factor.	D. F.	Sum of squares.	Mean square.
Ahmadabad	Regression	6	11,625	1,938
	Residual	32	21,809	682
	Total	38	33,434	796
Broach	Regression	3	6,025	2,008
	Residual	39	23,154	594
	Total	42	29,179	695
Surat	Polynomial	3	1,998	666
	Deviations from Polynomial	39	14,466	371
	Regression	5	4,016	803
	Residual	34	10,450	307
	Total	42	16,464	392

TABLE 9—*concld.*

Analysis of Variance

	Factor.	D. F.	Sum of squares.	Mean square.
Khandesh . .	Polynomial	3	2,439	813
	Deviations from Polynomial .	38	14,770	389
	Regression	6	7,091	1,082
	Residual	32	7,679	240
	Total .	41	17,209	420
Ahmadnagar .	Regression	5	6,157	1,231
	Deviations from Regression .	37	10,934	296
	Total .	42	17,091	407
Belgaum . .	Polynomial	3	2,697	899
	Deviations from Regression .	39	8,894	228
	Regression	5	3,749	750
	Residual	34	5,145	151
	Total .	42	11,591	276
Bijapur . .	Polynomial	4	4,939	1,235
	Deviations from Polynomial .	38	11,742	309
	Regression	6	7,994	1,332
	Residual	32	3,948	123
	Total .	42	16,681	397
Dharwar . .	Polynomial	3	7,443	2,481
	Deviations from Polynomial .	39	11,419	293
	Regression	4	3,713	928
	Residual	35	7,706	220
	Total .	42	18,862	449

We may now discuss the crop—weather relations of each district at greater length.

1. *Ahmedabad.*—Though the yield data for this district were available from the year 1889-90, only the data for 39 years from 1893-94 have been used because the maximum temperature data were available only from that year. The mean yield per acre is 77 lbs. of lint with a coefficient of variability 38 per cent. The values of x'_5 for the yield data given in Table 3 show no indications of secular changes.

Direct correlation coefficients of yield with July and September rainfall are positive and significant. The yield shows significant negative correlation coefficients with the maximum temperature of the four months September to December. It is, however, interesting to note that the mean maximum temperature of May gives a positive correlation coefficient of ·26 with the yield.

July and September rainfall and mean maximum temperature of September, October, November and December have been used to obtain the regression equation. Fig. 1-a shows the actual and calculated values of yield per acre in different years. The multiple correlation between them is ·596.

2. *Broach.*—43 years data from the year 1889-90 have been used for this district. It may be noted here that the condition estimate for the year 1918-19 is not given in the Season Crop Reports and the yield per acre as derived from the Final Crop Forecast have been utilised for this year. The mean yield per acre is 94 lbs. of lint which is the highest for the Bombay Presidency. The coefficient of variability is comparatively low being only 28 per cent. No significant secular changes are observed in this series. There having been no observatory in the district, the temperature data are not available. The rainfalls of August and September give significant positive correlations with the yield, July giving a fairly high positive value though not significant. Using only these three factors the regression equation gives a multiple correlation coefficient of ·45 which just exceeds the 5 per cent. level of significance. The actual and calculated values of yields are shown in Fig. 1-b.

3. *Surat.*—The average yield per acre over a period of 43 years commencing from 1889-90 is 87 lbs. with a variability of 23 per cent. The yield series shows indications of secular changes as shown by the values of x'_3 for the district given in Table 3. It may be noted that there are no indications of secular changes in the monthly rainfall of the district while the mean monthly maximum temperature data show indications of secular changes for the months of May, August, October and November. The yield data give a fairly high positive correlation with July and August rainfall and mean maximum temperature for May and negative correlation with August, October and November mean maximum temperatures. These five factors are used to obtain the regression equation for yield. The value of R the multiple correlation comes to ·53. The partial regression coefficient on the mean maximum temperature of May alone is significant and shows the beneficial effect of high maximum temperatures on yield. There are indications of adverse effect of mean maximum temperature of the month of October. The actual, polynomial and calculated values are shown in Fig. 1-c.

4. *Khandesh.*—The yield data for 42 years from 1889-90 have been utilised for this district. The district was separated into two districts East and West Khandesh from the year 1906-07 and the condition estimates are given separately from that year onwards. But in order to get a uniform yield series for the whole district from the beginning the average condition estimate weighted for acreage was adopted for the whole district from the year 1906-07 onwards, the standard out-turn being the same for both the sub-divisions. The mean yield per acre for 42 years is 75 lbs. of lint with a variability of 27 per cent. September rainfall gives a significant correlation of +·41 with the yield while the rainfalls of July and October show indications of relationship. Among the monthly maximum temperatures, there is a positive correlation between May maximum temperature and cotton yield. Excess of maximum temperature is May presumably helps the black cotton soil of the tract to plough itself better under the hot sun. September and October maximum temperature show significant negative correlation coefficients with yield while the correlation of November temperature with yields although negative and fairly high is not significant. Six factors namely July, September rainfalls and maximum temperatures of May, September, October and November have been utilised in evolving the regression equation which gives a significant multiple correlation of ·69.

The mean maximum temperatures of September, October and November are significantly correlated amongst themselves. Similarly September rainfall shows significant negative correlations with the September, October and November

mean maximum temperatures. In the regression equation, the partial regression of yield on May and October mean maximum temperatures alone show significance the first having a positive effect and the latter a negative effect. The actual and the calculated values are shown in Fig. 2-a.

5. *Ahmadnagar.*—The average yield is 48 lbs. with a high variability of 42 per cent. The series does not show any secular changes. It is seen from Table 6 that June and September rainfall and July, September and October maximum temperatures are significantly correlated with the yield. The regression equation gives a multiple correlation coefficient of ·60 which is significant. The comparatively low regression coefficient for September maximum temperature in spite of total correlation coefficient of ·39 seems to indicate that this apparent correlation coefficient is due to the indirect effect of the September rainfall and not due to the maximum temperature itself. Fig. 2-b shows the actual and calculated values of yield.

6. *Belgaum.*—The mean yield for 43 years from 1889-90 is 62 lbs. of lint per acre with a variability of 27 per cent. Significant slow changes of 1st and 3rd degrees are indicated in the series. September and October rains show significant positive correlations. October and November maximum temperatures show significant negative correlation with yield. The September maximum temperature also shows a negative correlation which is fairly high. The above 5 factors have been used in obtaining a regression equation which gives a significant multiple correlation of ·67. The actual, polynomial and calculated values are given in Fig. 3-a.

7. *Bijapur.*—The mean yield for 43 years from 1889-90 is 49 lbs. with a variability of 41 per cent. In this series it may be noted that the condition estimates for the years 1896-97 and 1899-1900 not being given, the corresponding figures from the final cotton forecasts have been adopted. These two years have been years of failure of the crop as seen from the extremely low values of the condition factor. Secular changes of 1st, 3rd and 4th degrees are observed in the series, as seen by the values of x'_2, x'_4 and x'_5 in Table 3. All the monthly rainfalls show positive correlations with the yield though the correlation coefficient for November rain is not significant. In view of this fact the temperature factor was not considered. The regression equation of yield on the rainfall of each month from June to November gave a high multiple correlation coefficient of ·83. This shows that in this district the rainfall of the monsoon months seem to exert a great influence on the yield of the cotton crop. Fig. 3-b shows the actual, polynomial and calculated values.

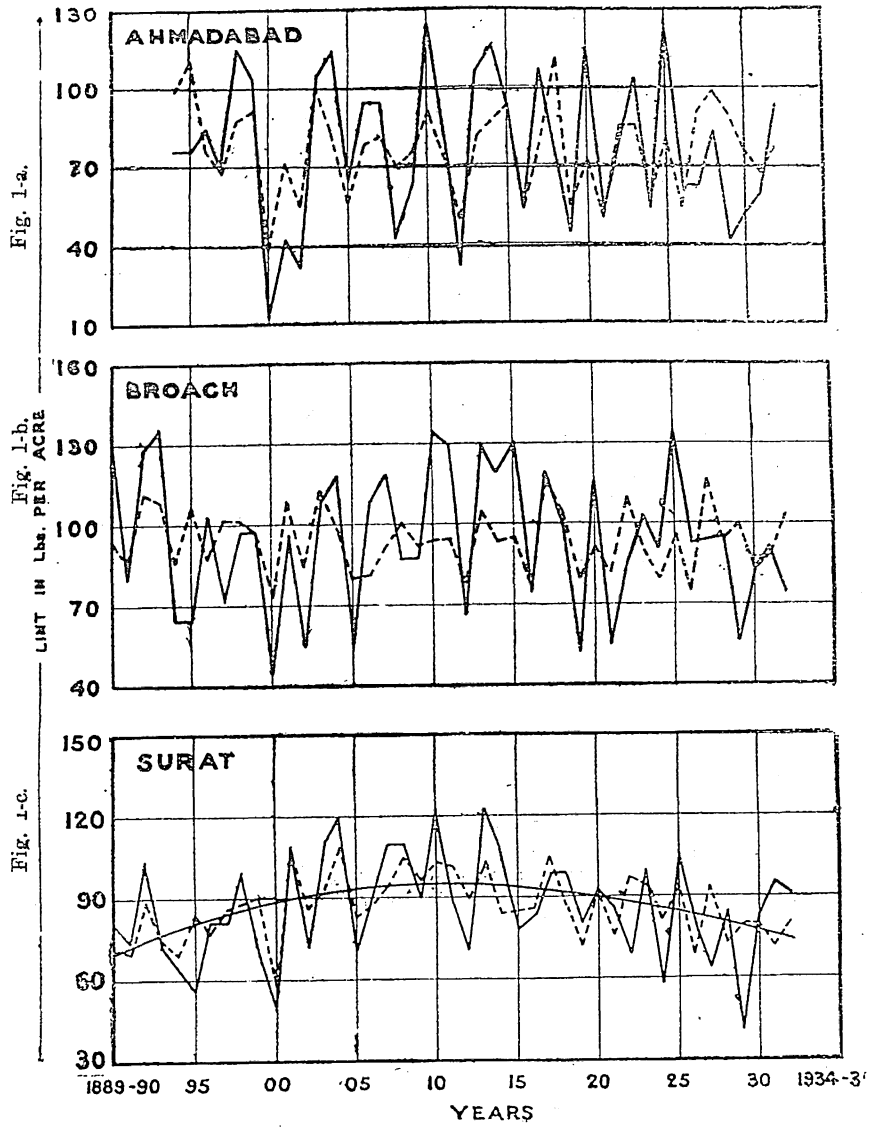
8. *Dharwar.*—This district has a mean yield of 69 lbs. with a variability of 31 per cent. The rainfall correlation coefficients with the yield are positive, those for August and September alone being significant. The value of the multiple correlation coefficient is ·57 using the rainfalls of July, August, September, and October. As there is no observatory inside the district no maximum temperature data have been tried. The actual, polynomial and calculated values are shown in Fig. 3-c.

Summary and Conclusion.—The Ahmadnagar and the Bijapur districts are most subject to the vagaries of weather. Other districts are not so liable to chronic drought although years of partial drought are numerous. The particularly bad years for one or more of the districts over the period considered were 1891, 1896, 1899 to 1903, 1911, 1918 and 1920 when the yield of cotton was very low for some of the districts.

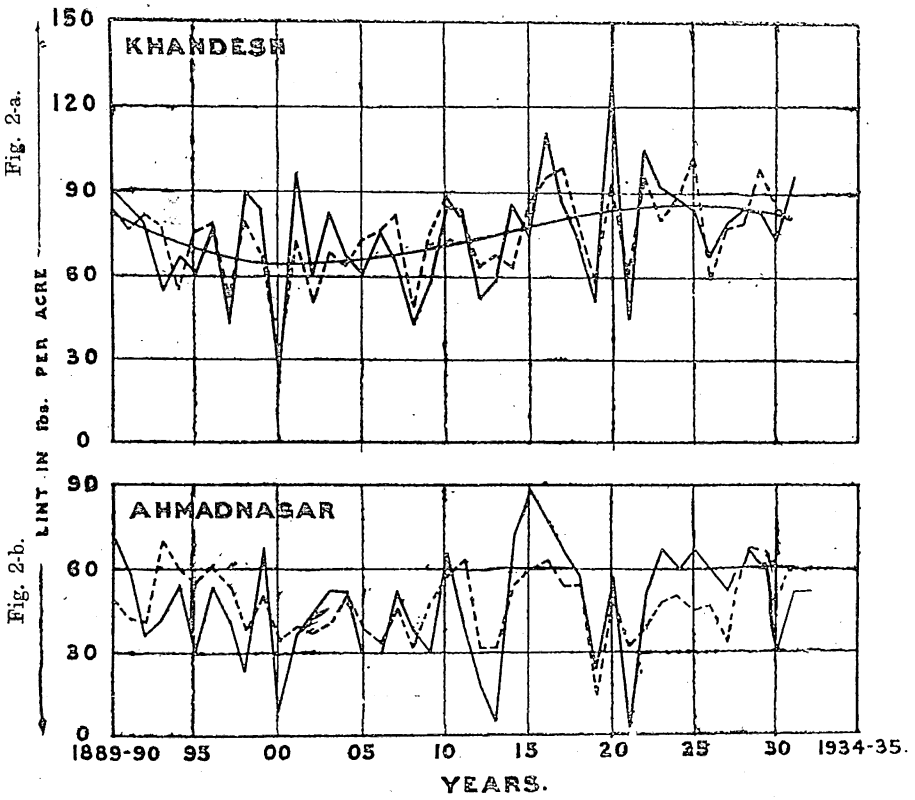
The coefficient of variability of yield is the highest for the Bijapur and Ahmadnagar districts, being of the order of 42 per cent. and is lowest for Surat with 23 per cent.

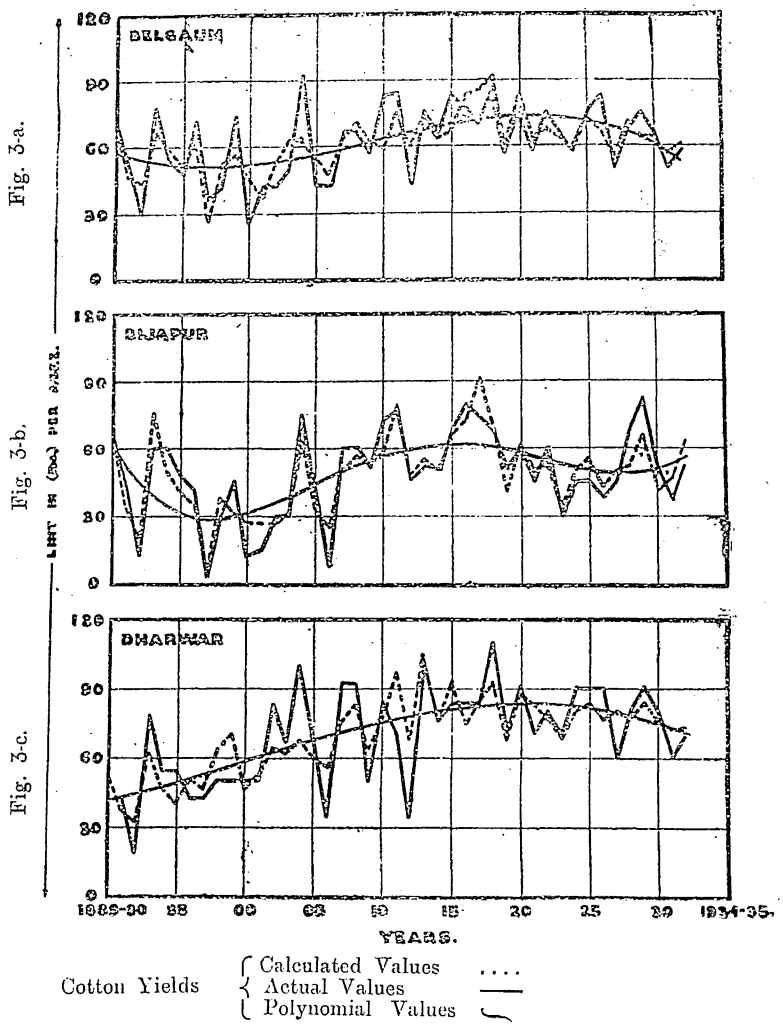
The yearly fluctuations in the yield per acre of cotton in the cotton growing districts of Bombay Presidency on the whole seem to be significantly attributable to the rainfall as well as to the maximum temperatures prevalent in the growing season. Rainfall is positively correlated. High maximum temperature of May in the case of Khandesh and Surat districts show a significant beneficial effect on yield which may be attributable to the fact that under the influence of the hot sun the black cotton soil " ploughs itself " and thus exercises a beneficial effect on the subsequent crop of cotton grown on it. Such beneficial effect of mean maximum temperature for the month of May is also indicated in the case of Ahmedabad district. Maximum temperatures above the normal show an avderse effect on the yield during the flowering and bolling period of cotton as is seen by the negative values of the correlation coefficients during that period.

The authors are thankful to Dr. L. A. Ramdas, Agricultural Meteorologist, for his criticism and guidance in the preparation of the paper.



Cotton Yields { Calculated Values .... / Actual Values —— / Polynomial Values. ~


KHANDESH
AHMADNAGAR
150
120
90
60
30
0
90
60
30
0
1889-90
95
00
05
10
15
20
25
30
1934-35.
YEARS.
LINT IN lbs. PER ACRE
Fig. 2-a.
Fig. 2-b.
Cotton Yields
Calculated Values
Actual Values
Polynomial Values


Fig. 3-a.
Fig. 3-b.
Fig. 3-c.
BELGAUM
BIJAPUR
DHARWAR
120
90
60
30
0
1925-26 28 30 32 34 36 38 40 1934-35.
YEARS.
Cotton Yields
Calculated Values
Actual Values
Polynomial Values

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APPENDIX A

AHMEDABAD (DISTRICT AVERAGE)

Monthly Rainfall (in inches)

Years	June	July	August	September
1893-94	12·5	10·2	5·4	6·8
-95	8·4	28·2	3·2	6·8
-96	5·5	9·4	8·4	1·2
-97	5·2	12·7	12·8	1·0
-98	2·7	9·1	8·8	5·7
-99	6·7	15·4	3·1	6·6
1899-00	4·3	0·2	0·5	0·9
-01	0·1	3·6	12·5	3·7
-02	1·0	7·3	6·7	0·6
-03	0·5	5·2	10·2	12·3
-04	0·6	14·1	5·7	3·5
-05	1·3	5·5	0·9	2·4
-06	0·4	25·5	0·7	3·0
-07	7·4	10·3	6·2	3·3
-08	2·9	9·8	19·9	0·3
-09	2·0	14·1	14·2	0·2
1909-10	4·8	12·0	7·9	4·5
-11	8·4	7·6	8·8	1·0
-12	4·9	1·3	1·3	1·9
-13	1·9	22·1	12·0	1·7
-14	9·8	13·8	4·6	5·4
-15	6·2	15·9	5·8	7·2
-16	3·2	3·5	1·4	1·0
-17	3·0	4·8	11·0	4·1
-18	3·2	10·6	11·1	11·2
-19	1·3	1·4	4·5	0·5
1919-20	3·2	7·7	13·0	1·9
-21	7·8	9·5	2·3	0·5
-22	0·2	13·6	6·6	1·6
-23	3·4	9·7	3·2	0·5
-24	0·3	6·5	4·8	0
-25	3·5	10·2	4·4	0·2
-26	8·1	7·6	2·1	0
-27	0·8	11·9	13·6	1·3
-28	4·4	39·5	6·1	0·2
-29	0·5	12·7	8·1	0·7
1929-30	3·7	10·2	4·9	0
-31	3·6	11·6	4·4	0·4
1931-32	0·3	7·8	17·5	0·4

Broach (District average)

Monthly Rainfall (in inches)

Years	June	July	August	September	October
1889-90	4·0	15·5	8·8	2·8	0·6
-91	10·7	6·1	5·1	3·8	0·2
-92	7·1	27·0	7·2	9·3	0·3
-93	6·0	11·5	11·0	10·5	0·4
-94	21·4	7·6	6·8	2·5	0·3
-95	12·2	23·1	3·4	12·5	10·1
-96	5·4	11·2	5·7	1·6	1·3
-97	7·0	32·3	6·9	1·5	0
-98	1·2	13·3	9·9	6·2	1·5
-99	11·3	20·0	4·3	6·1	0
1899-00	7·8	0·4	3·7	0·6	0
-01	0	6·0	17·8	6·4	0
-02	0·2	14·4	4·3	0·5	1·5
-03	2·0	13·0	11·5	11·2	0·1
-04	1·4	19·8	4·2	7·3	0
-05	0·8	5·9	1·4	4·7	0·1
-06	0·1	16·8	0·7	1·6	0·1
-07	10·6	11·0	8·6	3·1	0·2
-08	3·2	13·7	14·4	0·2	0
-09	2·0	16·4	7·7	1·1	0
1909-10	8·0	12·1	6·5	5·9	0·1
-11	11·4	14·3	9·4	2·0	0·5
-12	9·0	2·4	3·4	2·6	0
-13	4·8	26·3	11·3	1·0	0·2
-14	20·2	9·2	6·4	6·9	0
-15	11·5	12·7	3·3	9·8	0·6
-16	6·9	3·5	1·7	3·0	3·8
-17	4·4	9·0	16·1	11·0	2·3
-18	5·4	9·5	8·5	12·0	13·2
-19	0·8	7·9	3·4	0·3	0
1919-20	4·0	11·1	7·3	3·6	2·7
-21	6·5	7·8	3·5	1·9	0
-22	0·2	17·6	5·7	13·6	0·1
-23	10·0	8·9	2·4	9·7	0·4
-24	0·1	7·4	3·1	1·7	0·1
-25	4·1	9·9	8·8	5·3	0·5
-26	14·7	6·1	2·5	0·3	0
-27	0·7	15·2	13·9	10·5	0
-28	7·2	22·0	4·5	3·5	0·6
-29	4·3	14·2	7·5	7·6	1·3
1929-30	7·5	16·8	2·5	1·6	0·5
-31	13·5	12·6	3·7	5·5	4·1
1931-32	0·2	17·8	11·7	3·6	5·5

SURAT (DISTRICT AVERAGE)

Monthly Rainfall (in inches)

Years	June	July	August	September
1889-90	4·0	28·3	6·6	4·1
-91	25·6	15·7	8·6	11·2
-92	1·5	43·2	15·8	9·6
-93	7·9	29·6	17·9	22·8
-94	26·3	19·4	10·4	5·8
-95	16·1	37·3	7·0	12·6
-96	6·3	20·0	12·7	6·4
-97	12·0	36·5	13·2	3·8
-98	3·3	15·1	20·6	9·9
-99	13·1	23·1	7·7	10·2
1899-00	17·3	2·2	3·0	0·7
-01	0·7	22·7	29·2	6·6
-02	8·6	17·7	10·8	1·6
-03	1·9	24·0	19·5	14·0
-04	2·5	30·6	16·2	13·9
-05	3·1	10·5	7·2	7·6
-06	1·1	24·4	3·8	3·8
-07	10·9	22·6	11·2	3·9
-08	5·5	23·8	24·5	1·4
-09	5·1	38·8	14·7	2·7
1909-10	16·2	29·6	10·2	9·8
-11	13·7	14·5	20·2	4·6
-12	8·8	6·9	11·0	3·2
-13	8·3	45·3	12·2	3·0
-14	29·7	19·3	10·9	5·5
-15	19·3	32·0	7·3	16·3
-16	10·9	10·6	9·8	4·1
-17	7·5	14·5	20·9	13·9
-18	9·7	18·2	21·6	16·8
-19	3·9	11·6	13·4	1·0
1919-20	8·3	27·4	18·5	7·0
-21	8·7	16·4	9·5	3·6
-22	3·2	39·7	13·7	19·9
-23	12·6	23·6	5·6	19·7
-24	0·2	31·3	11·6	6·1
-25	8·0	16·7	17·2	8·9
-26	18·2	8·5	6·5	2·2
-27	1·4	32·7	29·6	13·8
-28	10·3	22·0	7·3	7·6
-29	2·8	24·1	11·2	9·9
1929-30	6·5	30·5	8·0	1·8
-31	17·4	28·2	7·5	7·1
1931-32	2·1	37·5	23·5	5·5

KHANDESH (DISTRICT AVERAGE)

Monthly Rainfall (in inches)

Years	June	July	August	September	October
1889-90	4·7	7·3	5·5	3·4	1·3
-91	6·8	6·3	6·0	5·5	0·4
-92	3·4	12·0	7·5	5·4	1·4
-93	5·3	6·7	8·6	13·4	1·3
-94	9·9	4·1	9·7	2·6	0·6
-95	5·7	11·7	2·2	9·2	5·2
-96	4·2	7·5	3·9	8·2	1·3
-97	5·9	15·9	4·5	0·5	0
-98	2·0	7·8	8·8	9·3	0·7
-99	4·0	9·3	5·1	7·7	0
1899-00	4·2	1·9	1·8	1·4	0
-01	2·7	7·9	8·7	4·6	0
-02	4·4	8·1	7·4	1·2	3·2
-03	2·4	7·1	4·7	6·0	1·6
-04	2·4	9·8	7·3	6·3	1·0
-05	2·7	4·2	2·4	12·2	1·2
-06	2·1	13·9	2·1	4·5	0
-07	8·3	9·5	7·3	3·6	0·1
-08	4·1	7·9	8·2	0·2	0
-09	4·6	9·6	7·7	2·5	0
1909-10	6·5	9·2	4·4	6·3	0·3
-11	9·1	8·0	8·4	4·3	2·0
-12	5·6	4·4	4·5	1·2	0
-13	3·3	10·8	6·0	0·6	0·4
-14	8·7	10·1	3·5	5·0	0·1
-15	10·9	11·5	4·8	11·9	0·5
-16	6·7	7·2	3·7	6·0	4·5
-17	6·1	10·8	8·0	6·9	3·0
-18	5·7	5·1	7·5	8·9	6·0
-19	2·7	4·5	4·6	0·7	0
1919-20	8·1	8·8	7·8	5·4	2·5
-21	4·1	7·6	3·9	2·0	0
-22	6·2	11·0	6·3	7·2	0
-23	6·1	7·3	2·0	7·2	0·4
-24	0·5	11·3	3·9	6·5	0
-25	3·1	5·9	7·6	6·8	4·4
-26	8·2	4·4	4·9	2·0	0·1
-27	1·8	7·7	11·4	3·3	0·1
-28	5·7	12·9	3·2	4·9	1·9
-29	3·8	9·1	5·3	6·2	2·3
1929-30	8·5	7·0	2·5	2·6	0·6
1930-31	6·5	7·8	4·6	11·9	0·7

AHMEDNAGAR (DISTRICT AVERAGE)

Monthly Rainfall (in inches)

Years	June	July	August	September	October
1889-90	2·8	3·4	1·4	11·3	4·9
-91	3·8	1·2	2·9	4·6	2·2
-92	2·5	3·1	3·1	3·8	2·5
-93	8·2	4·9	5·2	8·1	5·9
-94	8·6	1·1	3·7	4·4	1·9
-95	2·6	5·7	1·4	8·8	3·2
-96	3·8	3·8	1·3	11·9	1·6
-97	8·8	6·4	1·7	0·4	0·3
-98	1·3	2·8	2·2	10·5	3·8
-99	3·1	3·1	0·7	8·8	0·5
1899-00	4·7	0·3	0·8	4·3	0·1
-01	4·5	5·2	3·2	2·3	0·3
-02	3·4	2·3	2·5	2·7	2·3
-03	2·5	3·7	1·4	7·6	1·6
-04	3·2	6·8	3·3	4·2	4·0
-05	2·0	1·6	0·6	5·9	4·0
-06	3·1	3·3	2·2	0·9	1·7
-07	6·9	2·7	6·8	1·6	5·4
-08	3·2	6·8	3·8	1·9	8·6
-09	2·7	2·3	2·0	8·8	5·5
1909-10	6·1	1·9	3·5	6·1	1·0
-11	7·2	4·3	5·2	12·4	2·5
-12	3·7	5·3	2·2	0·2	0·1
-13	2·4	3·4	1·8	0·5	3·8
-14	8·0	4·1	1·3	1·8	1·6
-15	7·1	2·9	3·9	6·6	0·5
-16	7·2	6·9	1·0	9·2	2·9
-17	4·0	11·6	2·5	9·6	5·9
-18	4·8	1·2	4·7	8·9	5·0
-19	1·5	0·9	0·8	3·1	0·5
1919-20	4·7	3·3	1·2	10·5	0·6
-21	2·0	1·4	1·5	4·6	0·5
-22	3·5	6·7	0·8	4·5	0·7
-23	5·8	2·1	0·7	2·4	1·2
-24	1·3	4·8	1·0	8·9	0·4
-25	2·7	1·7	5·6	8·7	1·0
-26	4·4	1·2	3·8	4·2	0·5
-27	3·1	2·5	3·8	4·7	0·1
-28	7·9	5·0	0·5	7·8	2·6
-29	7·0	2·8	2·7	11·1	2·4
1929-30	5·0	1·3	0·4	5·8	3·3
-31	5·0	2·7	1·5	10·1	3·9
1931-32	5·9	4·6	1·4	6·2	5·4

Belgaum (District average)

Monthly Rainfall (in inches)

Years	June	July	August	September	October	November
1889-90 . .	7·9	6·5	5·0	8·7	8·8	0·4
-91 . .	6·0	14·7	4·4	2·6	3·6	4·6
-92 . .	2·3	12·6	8·1	0·9	5·3	0·5
-93 . .	6·4	12·5	6·5	7·2	9·0	0·5
-94 . .	9·4	4·0	6·9	2·8	8·9	2·9
-95 . .	7·4	14·2	5·2	2·7	4·3	0·4
-96 . .	8·4	7·6	6·0	7·5	4·9	1·4
-97 . .	12·3	14·3	11·7	0·8	1·0	0·6
-98 . .	6·3	12·0	8·0	5·0	4·9	0
-99 . .	8·1	11·7	3·3	7·2	6·5	1·4
1899-00 . .	7·4	2·9	1·4	6·3	1·5	0
-01 . .	9·5	15·8	14·6	1·4	2·3	0·1
-02 . .	7·3	9·5	6·0	5·2	3·4	0·3
-03 . .	7·2	11·4	2·9	3·9	6·5	1·5
-04 . .	5·6	15·7	4·1	4·4	4·4	0·9
-05 . .	11·6	8·7	4·5	3·6	3·5	0
-06 . .	4·3	8·2	4·1	1·3	3·6	0·6
-07 . .	5·8	9·8	7·6	5·6	3·4	1·3
-08 . .	3·9	9·5	14·9	9·5	8·9	0·9
-09 . .	4·5	17·0	7·0	5·6	1·2	0·1
1909-10 . .	6·6	14·8	4·2	4·0	3·8	1·1
-11 . .	6·7	6·2	10·6	5·4	5·0	1·1
-12 . .	7·1	6·5	5·9	1·9	5·0	0·3
-13 . .	3·9	23·0	8·9	6·0	5·7	0·8
-14 . .	8·0	8·8	5·4	3·8	3·2	0·1
-15 . .	4·2	24·3	18·9	5·0	1·4	2·5
-16 . .	8·8	10·8	4·2	7·4	2·3	2·0
-17 . .	6·9	8·8	7·1	5·9	6·9	9·7
-18 . .	8·7	4·8	5·5	6·7	6·8	3·7
-19 . .	3·7	2·7	5·4	3·6	1·8	3·3
1919-20 . .	7·4	7·3	5·0	8·2	3·7	2·8
-21 . .	5·4	11·4	3·7	4·4	3·1	0·2
-22 . .	5·8	10·3	5·9	1·7	7·1	6·0
-23 . .	5·7	11·3	4·8	1·5	3·2	4·9
-24 . .	2·1	21·7	8·7	3·3	0·3	0
-25 . .	5·0	15·8	6·9	5·0	1·8	0·3
-26 . .	7·2	13·1	3·7	3·0	4·2	0·6
-27 . .	4·3	13·8	11·8	3·9	1·2	0
-28 . .	6·3	15·0	4·0	8·3	1·0	2·7
-29 . .	6·7	11·1	6·4	3·8	4·7	0
1929-30 . .	6·1	9·2	3·7	8·3	4·6	0·7
-31 . .	7·1	8·5	4·6	4·6	8·2	0·8
1931-32 . .	5·2	13·2	10·8	4·3	3·6	3·2

Bijapur (District average)

Monthly Rainfall (in inches)

Years	June	July	August	September	October	November
1889-90	4·1	3·3	1·3	9·9	9·3	0·2
-91	3·4	1·3	2·9	5·8	3·6	4·9
-92	2·6	1·2	3·0	3·0	3·0	0·2
-93	5·5	3·9	7·6	8·6	10·6	0·7
-94	4·1	4·4	4·2	4·8	8·5	1·7
-95	2·0	2·4	5·0	8·5	3·9	2·0
-96	1·9	3·7	1·1	8·5	4·0	0·8
-97	2·1	1·9	1·6	1·5	0·2	1·7
-98	4·9	0·9	1·4	10·6	3·3	0
-99	4·1	2·1	1·0	7·5	3·5	2·3
1899-00	2·0	0·4	1·0	10·7	0·4	0
-01	5·2	2·9	1·0	3·0	2·3	0·2
-02	2·8	1·9	1·3	5·3	3·3	0·5
-03	4·7	0·9	3·0	4·4	3·4	1·3
-04	4·1	3·8	5·2	8·1	6·0	2·1
-05	2·3	2·0	0·7	5·6	3·3	0
-06	2·7	0·8	4·1	1·0	2·4	0
-07	4·3	2·3	5·8	3·6	2·8	0·6
-08	2·8	5·2	2·4	7·1	0	0·7
-09	1·9	1·3	1·9	12·0	0·2	0
1909-10	2·7	1·6	7·3	6·2	0·9	0·4
-11	1·3	5·5	7·3	7·7	3·3	1·5
-12	2·9	4·8	1·1	2·8	1·9	0·3
-13	1·8	3·3	4·1	3·7	3·8	0·7
-14	2·2	4·3	0·6	3·3	4·3	0
-15	1·6	3·1	6·2	6·4	1·1	1·4
-16	2·7	5·9	0·6	8·2	3·3	2·0
-17	3·1	8·8	2·2	8·5	8·0	10·5
-18	2·9	1·3	5·3	8·1	5·0	1·9
-19	1·7	0·4	0·9	6·3	0·7	1·6
1919-20	3·5	1·2	0·6	11·0	2·8	3·4
-21	3·0	0·6	1·9	6·7	1·2	0·1
-22	1·8	5·6	0·7	1·5	5·8	3·9
-23	2·4	1·8	1·2	0·8	2·4	3·7
-24	0·9	3·9	0·6	5·8	0·1	0
-25	3·1	0·9	2·8	7·8	1·4	0·2
-26	1·4	1·1	3·2	3·8	3·5	0·6
-27	2·3	2·4	1·3	6·8	0·3	0·1
-28	3·9	2·5	0·5	7·9	1·2	3·7
-29	5·1	2·2	1·6	8·7	4·9	0
1929-30	2·3	0·8	0·5	6·4	4·9	0·9
-31	2·4	0·9	1·1	7·9	4·6	0·6
1931-32	5·3	2·7	0·3	10·5	2·0	2·4

Dharwar (District average)

Monthly Rainfall (in inches)

Years	June	July	August	September	October	November
1889-90	4·3	4·1	1·5	11·1	5·8	0·5
-91	2·5	4·8	2·8	4·0	4·8	6·2
-92	2·0	4·4	3·0	0·6	5·5	0·8
-93	3·8	4·9	8·2	4·2	6·7	0·2
-94	5·5	2·8	3·7	2·1	8·4	2·7
-95	3·1	4·8	2·4	2·0	5·3	0·5
-96	5·5	3·4	3·1	4·6	5·6	0·5
-97	5·5	6·9	5·1	1·7	1·9	2·6
-98	6·3	4·3	4·6	7·3	3·5	0
-99	4·9	4·9	1·9	8·6	6·6	2·6
1899-00	3·9	1·7	0·8	5·7	2·1	0
-01	4·3	3·8	4·8	2·4	2·5	0
-02	3·5	3·8	2·6	5·8	4·6	0·5
-03	4·5	5·1	1·4	3·1	7·0	1·9
-04	3·9	5·6	3·2	3·7	5·2	0·9
-05	5·9	4·8	2·5	2·3	4·2	0
-06	3·5	2·3	3·9	0·7	3·5	0·3
-07	2·9	4·6	5·2	4·0	4·3	0·5
-08	4·1	4·0	6·1	8·5	0·8	0·7
-09	2·4	5·7	2·4	3·0	1·7	0·2
1909-10	3·3	6·2	5·3	2·7	3·6	0·7
-11	2·9	6·4	6·6	4·8	7·3	1·1
-12	3·5	4·6	2·4	1·8	4·0	0·5
-13	2·5	12·4	5·1	5·9	6·9	0·7
-14	2·7	4·6	1·4	4·4	4·1	0·2
-15	1·3	9·1	8·4	3·2	1·8	2·0
-16	6·6	5·8	1·8	4·7	2·1	2·2
-17	2·4	6·1	3·4	2·9	6·2	10·3
-18	4·4	2·5	4·5	6·6	5·4	4·2
-19	2·2	1·1	2·3	3·7	1·7	3·7
1919-20	4·9	3·3	2·4	6·6	5·2	3·1
-21	3·3	4·2	2·1	5·7	3·9	0·2
-22	2·1	4·8	2·3	1·6	6·1	2·8
-23	2·8	5·5	1·9	1·2	3·0	3·8
-24	1·5	9·7	3·9	3·5	0·9	0
-25	3·6	8·1	4·0	4·7	1·8	0·6
-26	4·1	4·5	2·9	3·5	3·8	1·3
-27	3·3	5·4	5·0	4·1	2·2	0
-28	2·5	6·0	2·0	6·8	0·7	2·7
-29	4·3	5·8	3·9	2·5	7·3	0·1
1929-30	3·7	3·6	1·8	6·6	3·7	1·5
-31	4·0	2·8	1·6	5·0	5·7	0·2
1931-32	4·0	4·1	4·9	5·3	1·4	4·8

APPENDIX B

AHMEDABAD

Monthly Maximum Temperature (in °F)

Years	May	June	July	August	September	October	November	December
1893-94	104·6	96·9	89·0	89·3	87·8	94·2	86·8	85·8
-95	106·1	97·2	85·6	88·5	90·1	92·8	89·2	84·3
-96	107·4	99·5	92·8	89·1	93·9	93·7	93·3	85·9
-97	108·4	98·4	91·2	86·3	94·2	100·1	91·0	86·6
-98	109·5	105·7	94·2	89·3	91·3	93·8	91·1	86·3
-99	107·6	99·6	91·0	89·2	90·8	97·9	93·5	84·1
1899-00	105·4	99·7	96·7	98·1	96·9	103·7	96·8	91·7
-01	106·8	107·0	99·7	87·7	90·8	97·5	95·5	87·4
-02	107·3	105·6	96·4	88·8	96·5	99·7	95·6	88·9
-03	108·0	103·6	98·3	94·4	89·5	95·7	92·2	84·3
-04	108·5	105·1	95·1	90·1	90·6	97·5	91·0	86·3
-05	108·0	102·8	92·3	93·1	97·2	100·8	94·1	87·7
-06	111·9	105·0	91·0	93·3	94·1	98·5	94·6	87·4
-07	110·7	100·0	90·9	89·5	89·1	96·1	94·6	86·9
-08	107·0	101·6	96·7	85·5	91·7	98·7	94·9	86·2
-09	105·7	102·0	88·2	85·8	93·3	97·1	92·8	85·4
1909-10	107·6	100·5	88·4	87·3	89·8	96·4	94·8	83·7
-11	107·1	95·9	90·5	88·5	93·3	95·7	90·6	86·2
-12	109·4	99·6	97·6	94·9	95·9	101·3	93·3	90·5
-13	109·5	105·1	91·0	87·7	93·1	97·6	90·1	86·7
-14	106·8	97·4	90·5	87·9	91·0	98·2	93·0	84·7
-15	107·2	100·5	89·8	90·8	91·4	95·8	93·2	85·0
-16	108·6	105·4	99·2	93·6	99·5	95·7	95·7	88·0
-17	109·9	102·1	96·4	89·4	93·7	94·4	91·0	86·5
-18	98·8	98·3	91·8	88·9	89·1	89·9	87·6	84·6
-19	107·0	102·2	97·8	93·9	93·8	102·7	96·8	85·9
1919-20	108·5	102·1	92·1	87·6	93·7	98·0	92·0	85·2
-21	104·6	97·3	92·0	92·8	98·6	101·4	95·8	88·1
-22	109·0	105·3	96·5	89·1	87·6	94·9	92·1	87·1
-23	107·0	103·5	98·3	93·9	87·7	95·9	91·1	84·1
-24	106·4	107·2	96·5	88·7	94·6	99·0	93·1	88·1
-25	107·7	103·1	95·1	90·7	90·6	93·6	90·0	85·9
-26	106·9	95·4	89·9	91·2	96·1	102·3	92·3	87·1
-27	106·0	107·1	92·9	88·0	87·8	95·0	89·3	84·4
-28	106·8	102·3	88·6	87·9	92·7	93·7	86·8	84·9
-29	107·8	103·9	92·0	89·8	89·7	94·6	91·3	82·7
1929-30	109·0	101·8	90·5	88·4	95·0	97·4	94·5	81·5
-31	106·1	99·5	88·1	88·3	94·3	97·6	90·2	87·2
1931-32	105·8	104·6	95·3	87·9	91·5	92·6	90·5	87·0

Surat

Monthly Maximum Temperature (in °F)

Years	May	June	July	August	September	October	November
1889-90	101·9	95·9	88·5	89·5	91·6	90·2	89·8
-91	100·2	91·7	85·8	86·7	88·7	92·6	91·6
-92	100·7	95·8	86·8	86·1	87·3	92·1	90·6
-93	97·6	92·3	89·0	87·6	86·4	92·6	90·0
-94	96·9	91·2	87·0	88·0	87·0	92·7	90·2
-95	97·4	92·1	85·1	87·5	87·9	89·5	87·2
-96	96·2	95·2	87·7	86·9	90·0	91·9	93·6
-97	95·7	91·5	85·5	84·5	87·6	94·3	89·5
-98	97·4	96·6	90·4	86·5	89·5	93·7	92·3
-99	99·8	92·6	88·0	86·8	89·4	97·7	95·7
1899-00	96·3	91·8	88·4	90·8	92·5	101·2	97·6
-01	99·9	95·9	92·3	85·1	89·3	96·5	95·5
-02	97·2	96·4	89·7	87·5	93·7	97·3	95·9
-03	98·1	95·5	90·7	89·7	87·5	94·8	92·3
-04	99·8	94·8	88·0	86·8	86·6	93·3	91·0
-05	95·7	93·6	87·8	87·3	89·8	95·5	92·7
-06	96·9	94·2	85·7	87·4	89·6	96·6	93·1
-07	96·5	91·4	86·5	86·5	86·8	94·5	94·3
-08	97·6	92·8	89·2	82·9	89·2	98·2	95·5
-09	94·4	92·7	84·2	83·6	89·6	94·5	91·2
1909-10	98·0	91·5	83·4	85·6	86·4	93·5	93·2
-11	96·6	89·2	86·0	85·0	88·0	91·8	88·1
-12	97·1	91·7	89·6	86·1	88·0	95·5	93·8
-13	97·5	95·1	86·2	85·4	89·9	95·7	90·3
-14	95·9	90·1	87·5	86·4	89·0	96·7	94·1
-15	95·9	91·0	85·9	87·5	87·3	95·4	92·4
-16	95·5	94·2	90·2	87·1	90·8	89·9	94·0
-17	98·7	91·0	89·3	85·4	88·3	90·3	89·5
-18	93·2	90·2	86·8	86·2	86·7	87·3	88·3
-19	95·3	91·7	88·6	86·7	90·3	99·3	95·4
1919-20	96·5	93·1	87·3	85·4	89·9	92·5	91·3
-21	95·9	91·9	86·3	86·3	90·9	96·2	95·2
-22	98·5	93·5	88·5	85·6	84·8	94·0	92·0
-23	100·0	92·4	86·2	84·7	85·0	95·0	90·5
-24	96·4	94·7	87·5	85·2	87·9	95·0	91·4
-25	98·9	93·2	87·5	86·2	87·3	90·4	89·0
-26	97·5	88·3	86·4	87·1	90·4	97·9	92·7
-27	98·6	95·3	86·4	85·3	85·8	94·1	90·7
-28	95·3	91·5	86·4	85·4	89·3	91·9	85·8
-29	97·5	93·0	86·4	86·1	86·3	92·4	91·9
1929-30	98·0	91·7	86·5	85·7	91·7	93·4	93·9
-31	96·5	92·3	84·3	85·0	89·0	95·1	89·5
1931-32	95·5	96·8	88·2	85·7	88·7	90·4	92·9

KHANDESH

Monthly Maximum Temperature (in °F)

Years	May	June	July	August	September	October	November
1889-90	107·4	96·5	88·3	84·9	91·2	89·2	86·7
-91	107·2	94·1	86·3	85·9	88·8	92·2	87·9
-92	106·3	103·1	87·8	84·4	85·4	89·4	86·4
-93	104·9	96·8	89·9	85·9	84·9	89·2	84·9
-94	102·6	92·7	89·3	85·0	86·2	90·3	86·1
-95	105·8	94·3	86·4	86·8	87·8	88·6	84·0
-96	107·1	96·4	90·0	87·1	88·7	91·1	91·1
-97	107·8	95·5	88·1	84·3	92·0	98·0	92·3
-98	109·4	102·4	93·0	87·1	88·6	91·5	87·6
-99	107·3	97·4	87·9	84·2	88·6	94·1	90·9
1899-00	105·4	96·2	90·1	93·2	97·1	101·0	95·0
-01	107·3	102·9	91·2	85·9	87·5	91·7	90·6
-02	107·2	101·5	88·9	85·0	92·4	96·3	89·8
-03	107·9	102·2	90·9	90·2	88·0	91·7	85·5
-04	104·6	102·7	89·2	87·5	87·1	91·2	87·3
-05	107·8	98·1	89·7	88·7	89·6	92·7	87·9
-06	110·5	102·3	87·6	87·3	88·0	94·3	89·1
-07	109·3	96·2	87·8	87·4	86·0	91·8	89·9
-08	106·1	99·9	91·5	83·4	92·1	98·0	91·9
-09	106·6	99·1	86·3	84·8	90·0	91·2	89·2
1909-10	106·6	96·3	86·5	88·1	87·4	89·1	90·4
-11	106·3	94·4	89·4	86·4	86·2	88·8	84·0
-12	108·9	99·1	91·4	86·1	89·4	96·7	88·7
-13	108·6	105·1	90·2	85·8	92·1	94·8	87·2
-14	105·8	95·4	88·1	86·5	90·3	96·4	91·2
-15	107·8	97·1	86·2	86·7	87·9	93·4	89·3
-16	108·4	104·6	91·9	86·2	90·3	90·4	89·9
-17	109·2	93·6	90·5	86·9	89·1	89·1	85·4
-18	99·8	96·5	87·8	88·6	86·4	86·4	84·9
-19	105·6	96·3	92·6	86·9	92·9	98·3	92·1
1919-20	107·2	95·8	89·2	85·9	90·5	91·0	89·6
-21	104·9	99·5	88·1	88·8	92·6	97·9	92·0
-22	108·9	97·1	90·2	87·2	86·5	92·9	88·6
-23	107·3	98·6	86·6	88·1	87·6	93·7	84·9
-24	106·4	104·3	87·9	85·0	88·6	92·6	89·8
-25	107·7	101·8	89·8	88·4	88·2	87·6	84·7
-26	104·9	95·3	87·6	87·0	92·3	96·9	87·8
-27	106·1	105·6	90·3	85·5	89·5	94·2	88·6
-28	106·9	99·1	87·1	87·9	91·8	91·9	81·7
-29	108·1	99·2	87·9	88·3	88·4	91·4	89·9
1929-30	108·9	97·8	88·9	88·6	91·0	94·5	91·6
1930-31	106·6	99·1	87·2	86·4	89·1	93·6	86·0

AHMADNAGAR

Monthly Maximum Temperature (in °F)

Years	May	June	July	August	September	October
1889-90 *	101·6	92·4	85·5	85·0	85·2	88·8
-91	85·1	85·5	86·1	84·1	86·1	88·1
-92	101·5	97·8	85·5	85·2	84·3	86·8
-93	100·5	88·3	83·6	82·4	81·2	85·2
-94	97·2	85·2	85·0	82·1	83·3	86·2
-95	100·4	90·2	84·0	86·0	82·0	84·6
-96	102·2	90·0	84·9	83·9	84·1	84·7
-97	102·8	87·3	82·7	81·3	85·8	94·7
-98	104·6	96·5	88·7	86·6	87·0	85·7
-99	101·7	92·2	84·6	85·3	84·9	89·2
1899-00	100·0	89·9	87·0	90·8	89·9	85·0
-01	103·2	95·9	86·0	83·4	87·8	90·0
-02	100·4	93·5	86·1	84·0	89·9	90·9
-03	102·8	94·6	86·6	88·4	84·7	88·4
-04	98·6	95·0	83·6	84·4	85·3	86·7
-05	102·6	92·0	86·5	87·5	87·0	87·7
-06	106·3	95·0	85·4	85·7	88·7	92·6
-07	105·5	91·1	85·4	85·5	85·6	90·6
-08	102·1	93·6	86·1	80·6	88·4	93·3
-09	102·7	93·3	84·8	83·4	85·4	89·8
1909-10	101·4	89·8	84·3	87·5	84·7	87·6
-11	101·8	90·5	86·4	82·7	81·8	85·9
-12	104·3	90·4	85·6	81·7	88·2	93·9
-13	103·7	97·9	86·1	84·6	92·0	91·1
-14	101·8	89·2	84·2	84·6	88·3	90·8
-15	103·6	91·5	83·7	84·9	86·5	90·5
-16	102·0	96·6	85·2	84·5	85·6	85·5
-17	102·7	88·8	86·0	84·5	85·5	85·1
-18	96·5	91·9	86·8	85·6	83·9	82·4
-19	97·2	92·2	89·8	86·6	88·5	93·8
1919-20	103·1	91·0	86·9	85·5	87·4	88·9
-21	101·5	93·9	86·1	88·2	89·4	93·7
-22	105·0	92·9	86·4	86·4	85·1	88·9
-23	101·7	91·9	84·4	85·6	86·4	90·9
-24	102·6	98·4	83·8	84·2	85·6	88·7
-25	103·7	94·2	86·9	86·4	85·2	85·6
-26	99·2	90·3	84·1	84·7	87·5	91·5
-27	101·2	96·9	87·3	84·0	87·1	90·4
-28	101·8	91·4	83·4	85·6	87·4	87·5
-29	102·3	92·8	84·8	85·9	83·8	86·4
1929-30	102·7	91·2	85·7	86·5	88·3	88·0
-31	102·0	92·9	83·9	85·4	85·8	88·5
1931-32	103·6	96·2	85·2	85·4	86·3	84·0

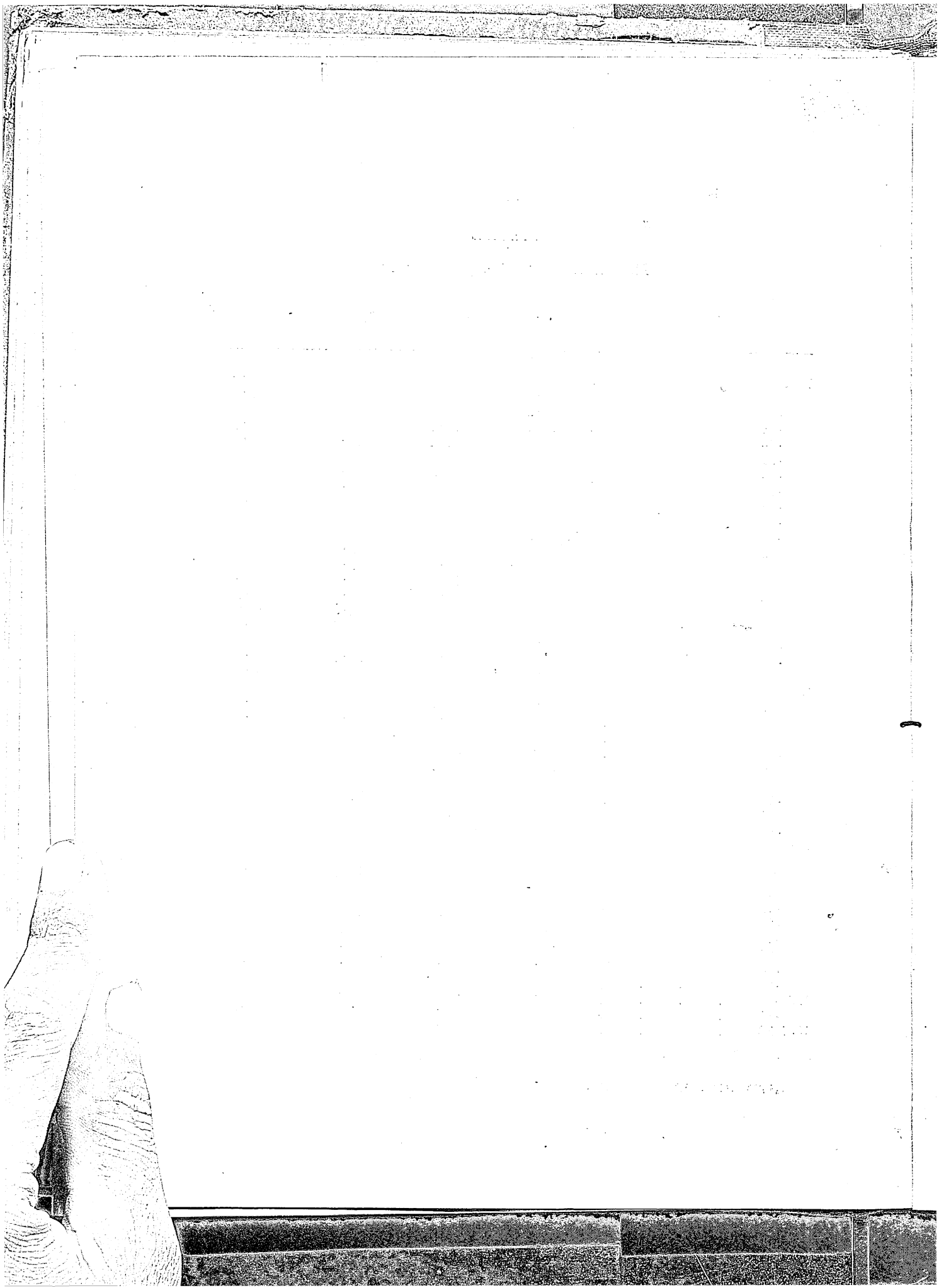
* As the Observatory was started only in 1890 the averages over the period 1890 to 1931 are assumed for 1889.

Belgaum

Monthly Maximum Temperature (in °F)

Years	September	October	November	December
1889-90	81·2	80·1	82·6	82·8
-91	78·7	83·3	81·9	82·7
-92	78·2	83·4	83·0	82·8
-93	76·1	81·1	80·2	81·1
-94	77·7	81·1	79·6	79·3
-95	77·6	81·5	80·4	82·0
-96	79·1	82·5	83·1	80·6
-97	83·6	88·7	86·7	84·7
-98	80·9	83·1	84·6	82·4
-99	79·7	84·7	81·7	82·5
1899-00	80·3	86·9	86·0	83·6
-01	79·4	85·7	85·0	84·5
-02	81·6	84·3	82·5	82·6
-03	78·5	82·6	80·4	78·7
-04	79·9	81·4	81·8	81·1
-05	78·6	84·2	82·9	81·3
-06	80·2	84·4	84·9	83·5
-07	77·7	82·9	82·6	82·1
-08	79·5	86·0	84·7	82·1
-09	79·5	84·8	83·4	81·2
1909-10	79·1	84·7	84·6	83·0
-11	77·3	80·6	79·0	81·2
-12	78·6	83·5	84·0	82·3
-13	80·3	82·4	80·9	81·2
-14	80·1	83·5	84·6	83·8
-15	78·7	84·7	81·9	81·6
-16	80·0	81·2	82·1	79·7
-17	78·3	80·9	77·6	78·9
-18	77·3	77·8	80·2	80·2
-19	80·5	87·8	83·7	82·5
1919-20	79·5	82·6	81·9	80·9
-21	80·7	84·8	85·4	85·2
-22	77·7	84·1	80·9	82·1
-23	78·4	84·7	81·4	81·0
-24	79·5	85·5	86·3	84·0
-25	79·1	81·4	82·1	82·5
-26	81·1	84·6	84·6	80·0
-27	79·4	85·8	85·8	84·7
-28	81·0	83·0	81·0	83·0
-29	79·1	82·9	84·7	81·3
1929-30	81·9	83·9	84·1	84·6
-31	80·2	83·7	82·9	84·8
1931-32	78·9	81·3	82·5	80·0

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Micro-Climatology in relation to Crops.*

By R. J. Kalamkar.

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IN a recent note[1] the importance and scope of micro-climatological studies were discussed. The present note is a continuation of the above with special reference to conditions inside crops as compared to those in the 'open'.

INFLUENCE OF VEGETATION ON MICRO-CLIMATE.

Not only does the climate of a place determine what crops or vegetation would thrive there but also the latter in their turn modify the climate and in particular the "micro-climate".

The influence of plants on "micro-climate" would depend upon the nature of plant surfaces, the convective processes in the neighbourhood of plants and the height and density of vegetation.

A surface of vegetation greatly alters the thermal conditions of the earth. Plant surfaces absorb solar radiation. A part of the absorbed energy is utilised in transpiration and photosynthesis while the rest of the energy goes to increase the temperature of the plant material which also loses part of the energy by emission of thermal radiation. Transpiration and evaporation from plant surfaces also play an important part in controlling the distribution of moisture in the air layers near the ground.

The convective processes in the neighbourhood of plants differ from those in the open. Inside vegetation air movements are feeble and loss or gain of heat by convective processes is correspondingly suppressed.

Apart from the direct effect of solar radiation on plants there is also the shading effect of plants on the surface of the soil according to the density of foliage. This decreases ground heating. The micro-climate is influenced by the height and density of vegetation and therefore by the stage of growth of a particular crop during the growing season. Four stages in the evolution of plant climate may be broadly distinguished.[2]

In the first stage the seeds have just sprouted, the ground is yet bare and so the micro-climate is not essentially different from that over bare ground.

In the next stage, there is a lateral spreading simultaneously with vertical growth, with complete shading of the ground. The seat of diurnal transfer of heat is still near the ground but the micro-climate differs from that over bare ground. The temperature range at the ground is now considerably reduced.

In the third stage plants grow in height and foliage is more uniform with height. An interspace between the ground and the surface of vegetation is also created. The top surface of the crop absorbs solar radiation during day and radiates heat during night. It therefore acts as a second active surface besides the ground.

In the final stage, *e.g.*, in case of a forest, the foliage near ground is less, the second active layer is raised farther from the ground and appreciable air movement is possible in the interspace.

MICRO-CLIMATIC OBSERVATIONS INSIDE CROPS.

Measurements of air temperatures and humidity at various heights are being taken daily inside a few crops and in the 'open' in the Agricultural Meteorological Observatory, Poona, at the epochs of maximum and minimum temperature by means of an Assmann Psychrometer. Observations in the 'open', jowar, and sugarcane, indicate that while pronounced differences are found in the micro-climates of these crops as compared to the 'open' at the epoch of maximum temperature, the differences are not so great at the epoch of minimum temperature.

MAXIMUM TEMPERATURE EPOCH.

It may be observed that at the maximum epoch, the dry bulb temperature in the 'open' is very high near the ground and falls rapidly with height during clear weather. Temperature inside jowar near the ground is lower than in the 'open', but at higher levels it is slightly higher than at corresponding heights in the 'open'.

In the case of sugarcane (an irrigated crop) the dry bulb temperatures near the soil are much lower than those in the open as well as those inside jowar (an unirrigated crop) and they have a tendency to increase with height, but even at 6 ft. it is about 2° lower than that of the 'open'. The largest difference between 'open' and sugarcane is 14°C. near soil, 5·5°C. at 2 ft., and 3°C. at 4 ft.

There is a tendency for vapour pressure to decrease rapidly with height and inside crops the moisture content is higher at all heights than in the 'open'.

MINIMUM TEMPERATURE EPOCH.

Variation of micro-climate is much less at the epoch of minimum temperature. The dry bulb temperature decreases at first with height both in the 'open' and inside crops and then begins to increase, the level of inversion being about 6" in the 'open' and about 2 ft. inside jowar and sugarcane. Temperatures inside jowar and sugarcane are higher than in the 'open' but tend to the open air value at higher levels.

Vapour pressure in the 'open' is throughout less than that inside crops. In the 'open' as well as inside jowar it increases with height. In sugarcane, however, it decreases with height in the lower levels but variation is negligible after 3 ft. Vapour pressure inside sugarcane continues to be higher than in the 'open' and inside jowar at this epoch also.

CORRELATION OF MICRO-CLIMATE OF CROPS WITH THAT OF THE 'OPEN'.

It would also be interesting to investigate whether the conditions inside crops could be expressed in terms of those outside. If the correlations are high and significant, then past observations in the open may be adjusted so as to give conditions inside crops. Analysis of some of the results for tall crops show that the morning correlations of dry bulb, vapour pressure, wet bulb and relative humidity inside the crops with

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* Report of a lecture at the Colloquium, Meteorological Office, Poona, on the 26th June 1934.

[1] L. A. Ramdas, "Micro-Climatology," *Curr. Sci.*, 1933-34, **2**, 445.

[2] Von Dr. Rudolph Geiger, "Microklima und Pflanzenklima," *Handbuch der klimatologie*, 1930, Band **1**, Teil D.

those in the 'open' are uniformly high, whereas those for the afternoon are smaller, especially at lower levels.

Further studies on these lines and for different crops have to be continued at a few representative centres before definite conclusions could be drawn. The results obtained so far are being discussed in detail elsewhere.



Influence of Weather and Prices on the Cotton Crop of the Bombay Presidency.

ONE of the aims of the Agricultural Meteorology Branch, Meteorological Office, Poona, is to investigate statistical relationships between weather and crops. The cotton crop was taken up to begin with and the analysis has been completed for the Bombay Presidency which occupies nearly four million acres, about one-fourth of the total cotton acreage in India.

Cotton Tracts of the Bombay Presidency.—The cotton belt of the Presidency, excluding Sind, can be divided into four distinct tracts defined by the character of soil and season and consequently also by the type of cotton grown in them though they naturally grade off into one another. These tracts are :

(i) The South Gujarat with 30″—40″ of annual rainfall.

(ii) Karnatak with 20″—30″ of annual rainfall.

(iii) North Gujarat with 25″—30″ of annual rainfall.

(iv) Deccan Tract with 20″—30″ of annual rainfall.

Sources of Data and their Limitations.—The figures of acreage, yield and price have been taken from the *Season and Crop Reports* of the Bombay Presidency and the meteorological data from the records of the India Meteorological Department. While the official statistics of area sown are fairly accurate, the data of yield per acre have certain limitations. The detailed examination in recent years of the official forecasts, the returns of cotton ginned and pressed, trade statistics, by the Indian Central Cotton Committee, has conclusively shown that the yield of cotton has in general been underestimated. It cannot be expected, therefore, that the statistical analysis of the "yield per acre" and weather factors would indicate anything more than certain general relationships.

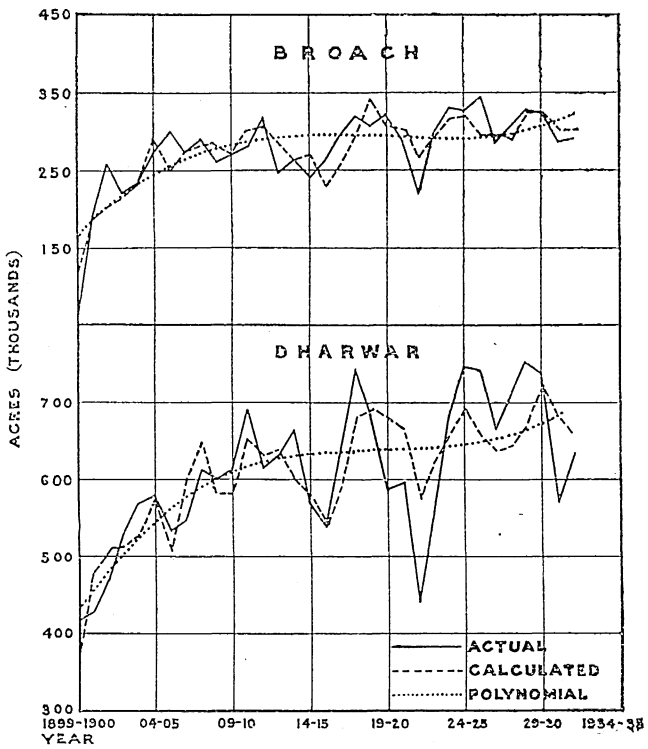
Secular Changes and Variability.—The area and yield data for cotton of important districts of each of the above tracts have been examined. Some interesting results as regards the influence of weather on area and yield and also the effect of the prices of cotton on area sown have been obtained. Significant trends in the area, yield and prices have been noted in the data extending over a period of 43 years commencing from 1890. The mean acreage and its coefficient of variability are given for different districts in columns 2 and 3 of Table I below. It is interesting to observe that the area under cotton in Ahmednagar is very variable and seems to depend mostly on the timeliness of the early rains.

TABLE I.

District	Mean area sown (thousands of acres) 1890-1932	Coefficient of variability
Khandesh ..	1,229	8·2
Ahmednagar ..	116	54·5
Belgaum ..	206	23·1
Bijapur ..	500	30·0
Dharwar ..	567	12·9
Ahmedabad ..	328	29·2
Broach ..	269	14·9
Surat ..	134	15·5

Correlations of Area with Prices and Rainfall at the Time of Sowing.—Correlations of 'area' with 'prices and rainfall at the time of sowing' have been worked out for the above cotton-growing districts. Prices rather than rainfall seem to dominate the area sown to cotton in the Khandesh, Ahmedabad, Broach and Dharwar districts while in the Surat district both the rainfall and prices show significant correlations. In the districts of Ahmednagar, Belgaum and Bijapur significant correlations between area and rainfall at the sowing time are obtained while those between area and prices are insignificant. Formulæ have been worked out for calculating the cotton acreage from prices and rainfall at the time of sowing. Fig. 1 shows the actual and calculated acreages in the Broach and Dharwar districts for a period of 33 years.

Influence of Rainfall and Maximum Temperature on the Yield of Cotton.—The limitations of the yield statistics have already been referred to. Use has been made of the past data as available for studying the influence of weather factors on the yield of cotton. Significant correlations of



COTTON ACREAGE.

Fig. 1.

AREA.

Factors used.

(1) Broach District { Sowing—June, July. Harvesting—February, March.

June Rainfall and average price of Broach variety during the seven months January to July, prior to the sowing season.

(2) Dharwar District { Sowing—September. Harvesting—March, April.

September Rainfall and average price of Dharwar variety during the seven months January to July prior to sowing season.

Fig. 2.

~~AREA.~~ yield.

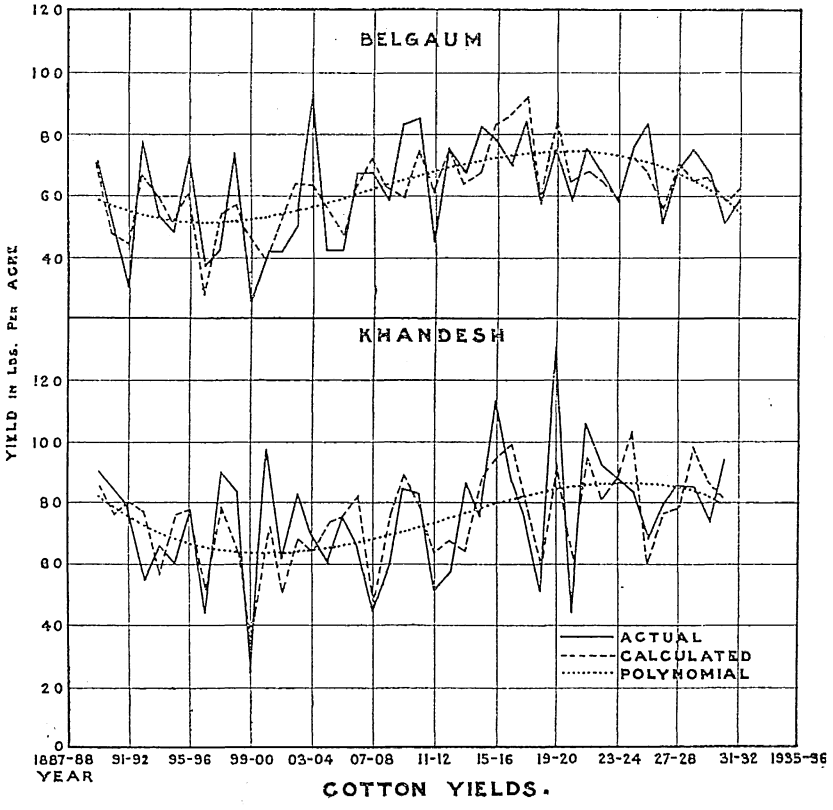
Factors used.

(1) Belgaum District
Sowing—August, September.
Harvesting—February, April.

September and October Rainfall and October, November and December Maximum Temperatures.

(2) Khandesh District.
Sowing—June.
Harvesting—November, December.

July and September Rainfall and May, September, October and November Maximum Temperatures.



COTTON YIELDS.

rainfall and maximum temperature with cotton yields have been obtained for the cotton-growing districts. The actual and the calculated values for Belgaum and Khandesh are given in Fig. 2. The results will be discussed in greater detail elsewhere.

Investigations on other crops will be taken up.

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Agricultural Meteorology Branch,
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Poona,
December 11, 1935.



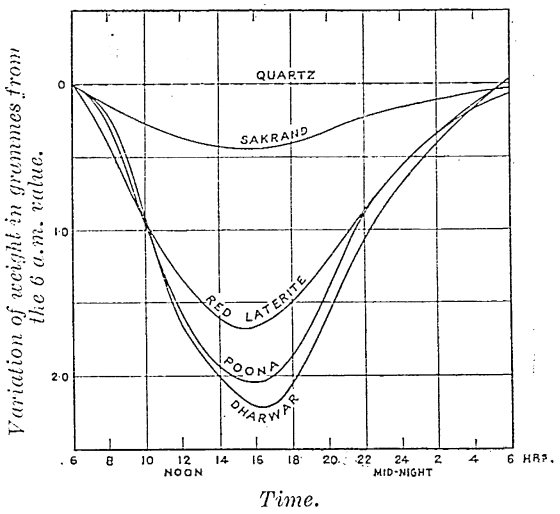
Reprinted from "Current Science", Vol. IV, No. 7, pages 484-486.

Reprinted from "Current Science," Vol. III, No. 1, July 1934, pages 24-25.

The Variation of Moisture in the Surface Layer of the Soil in relation to the Diurnal Variation of Meteorological Factors.

IN a recent note[1] one of us referred to the decrease in the pressure of water vapour with height above bare soil during day and the reverse phenomenon at night. These effects were observed daily at Poona during the clear season, November to April, when the surface layer of the soil is dry and contains only hygroscopic moisture. Experiments with samples of the surface soil exposed under natural conditions (in the open) showed that there was appreciable loss of weight by evaporation during the day and that most of the moisture lost by day was regained from the atmosphere during the night. These results readily explain the humidity observations, for, during the day, owing to insolation and consequent rise in temperature, the soil surface gives up moisture to the atmosphere, whereas during the night it absorbs moisture from the air layers above it and thus reduces the vapour pressure in these layers.

Soil samples from a few other centres were next exposed in a similar manner and their weights determined at two-hourly intervals. The weights of the soils were of the order of 60 grammes, the area of cross-section of the vessels used being 30 square centimetres. Observations of air temperature, humidity, soil temperatures, wind velocity and intensity of radiation from the sun and sky received by a horizontal surface were also made simultaneously. The figure shows the variation in the weights of the different samples from 6 A.M. of 1-6-1934, to 6 A.M. of 2-6-1934, the variations being expressed with reference to the weight of each sample at 6 A.M. It is interesting to note the very high amplitudes of the evaporation during day and the absorption during night in the case of soils from Poona and Dharwar. Soil from Sakrand showed a moderate variation. The weight of each sample is maximum at the minimum temperature epoch (about 6 A.M.) and minimum at the maximum temperature epoch (about 2 P.M.). A sample of quartz powder, however, showed hardly any variation. The responses of different soils to the diurnal variation of meteorological factors appear to offer an interesting method of studying the hygroscopic properties of different soils and their influence on the micro-climate.

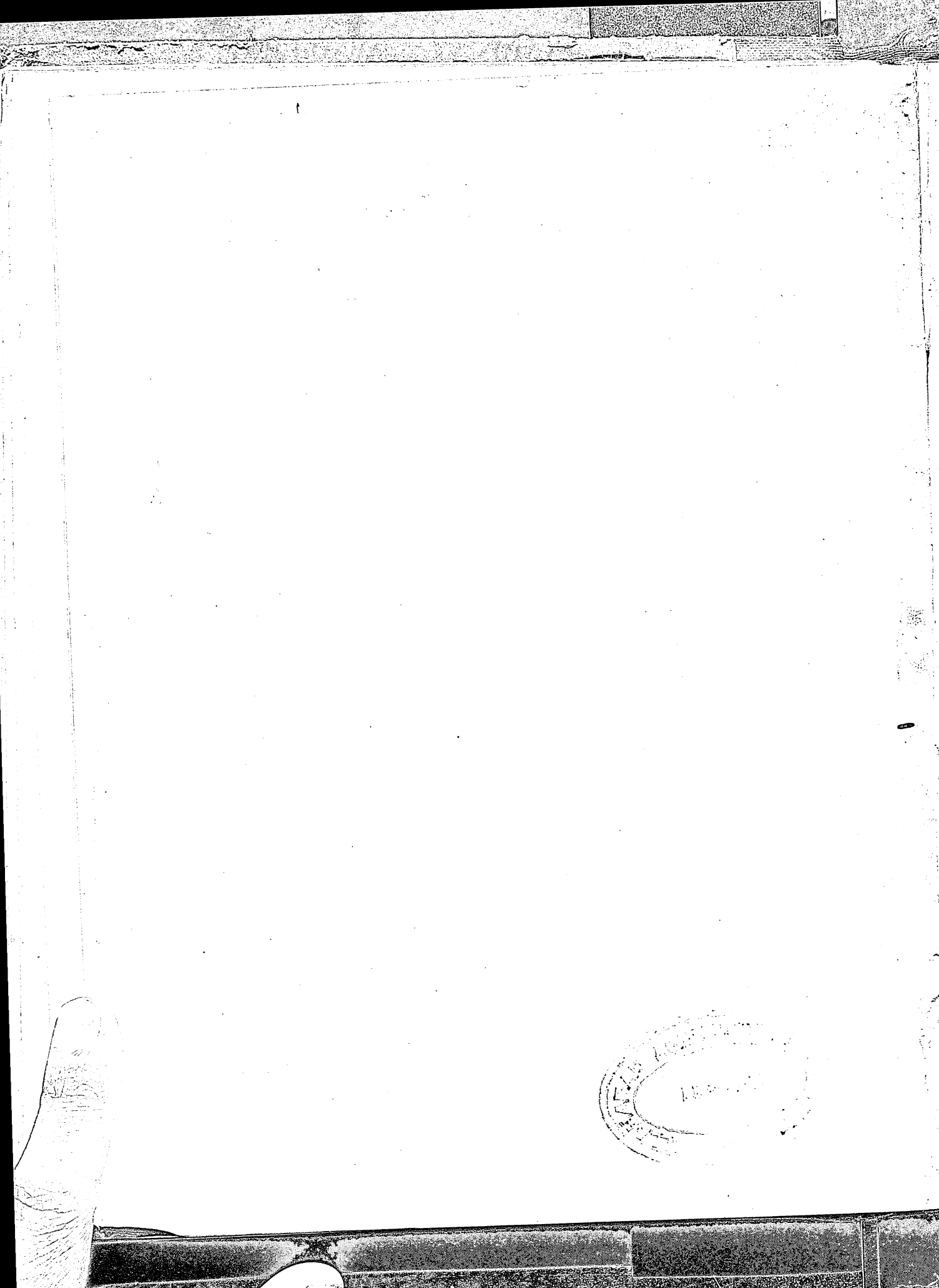


Further work with different soils is in hand. The results obtained so far are being discussed fully elsewhere.

L. A. RAMDAS.
M. S. KATTI.

Agricultural Meteorology Branch,
Meteorological Office, Poona,
July 6, 1934.

[1] *Curr. Sci.*, 1934, **2**, 445.



SOIL TEMPERATURES IN RELATION TO OTHER FACTORS CONTROLLING THE DISPOSAL OF SOLAR RADIATION AT THE EARTH'S SURFACE.

By L. A. Ramdas, *Agricultural Meteorologist and* R. K. Dravid, *Research Student, Meteorological Office, Poona.*

(*Read July* 19; *received August* 21, 1936.)

1. Introduction.

The temperatures attained by the surface layers of the soil depend upon a number of factors which control the disposal of solar radiation at the earth's surface. These factors are enumerated below :—

(i) The duration and intensity of the total radiation from the sun and the sun-lit sky received by unit area of a horizontal surface.

(ii) The colour of the soil surface which determines what fraction of the incident energy is absorbed by the surface.

(iii) The thermal conductivity of the soil which depends upon the chemical composition, the water content and the pore space (or apparent density).

(iv) The heat transfer from the heated soil surface by convective processes in the air layers near the ground.

(v) The radiative exchange in the long wavelength (or infra-red) region of the spectrum between the soil surface and the atmosphere.

To determine the heat balance at the earth's surface it is necessary to make systematic measurements of each of the above factors. The Central Agricultural Meteorological Observatory at Poona, which was founded in 1933 under the auspices of the Imperial Council of Agricultural Research, has been provided with the equipment necessary for a complete scheme of observations. The special investigations on radiation and convective heat transfer have been conducted with the assistance of Mr. P. K. Raman and those on soil temperatures with the help of the junior author of this paper.

In the present note we shall briefly mention some of the interesting results on the thermal balance at the surface of the ground obtained by Mr. Raman and then summarise the main results of the soil temperature experiments conducted during the last two years. We shall confine our attention to the clear season at Poona (November–May) when the climate is of the simple continental type, with clear skies and light winds. Mr. M. S. Katti [1,2,3,4,5] working at the observatory at Poona has shown that, during this season, the soil surface loses moisture by evaporation during the day time but re-absorbs moisture during the night from the

air layers near the ground so that the net loss by evaporation is negligible. We may therefore leave out phenomena like precipitation and evaporation from the present discussion.

2. Thermal Balance.

(i) The total radiation from the sun and sun-lit sky received by unit area of a horizontal surface during each day can be computed from the records of a self-registering Kipp and Zonen solarigraph. The energy so received varies roughly from 900 gramme calories in summer to 200 gramme calories during the monsoon season.

(ii) Of the above radiation only 86% is absorbed by the black cotton soil, 40% by alluvial soil from the Indo-gangetic plains, 60% by a grass covered soil, and as much as 94% by a surface covered with charcoal powder. At Poona during the summer on clear afternoons, the surface temperature in the black cotton soil often goes up to 75° C.

(iii) The heat carried away by convection during the course of a single day from the surface of Poona soil has been determined experimentally by a new method by Raman[6]. He estimates that the convective heat loss varies between 175 and 340 gramme calories during the clear season.

(iv) The ground surface radiates more or less like a black body in the far infra-red region of the spectrum in which bodies at ordinary temperatures radiate. The energy so radiated is merely a function of the surface temperature ; from the record of a thermograph recording the surface temperature of the soil one can easily estimate the heat radiated to the atmosphere by the ground surface during the course of a single day.

If the atmosphere were quite dry all the energy radiated would be lost to space ; fortunately, owing to the presence of water vapour, an appreciable portion of the heat radiation is absorbed and re-radiated by the different layers of the atmosphere. The total heat radiation received by unit area of a horizontal surface from the night sky has been measured during the last few years at Poona. A discussion of these data will be found in a series of papers published recently[7,8,9,10].

(v) We are left now with (i) the thermal current flowing downwards into the soil during the day hours when the soil surface is warmer than the layers below, and (ii) the thermal current flowing upwards towards the soil surface at night soon after the latter becomes cooler than the soil layers below as a result of radiative cooling. The total amount of heat leaving the surface during the day and returning to the surface from the soil during the night due to conduction may be computed from a knowledge of the variation of the soil temperature with depth and with time during each day.

An account of the gain and loss of thermal energy at the surface of the ground due to the various processes enumerated above is given in the table below (Table 1) for a typical day in March, 1934 at Poona.

TABLE 1.

The Thermal Balance Sheet—March, 1934.

PROFIT.		LOSS.	
Item.	Gramme calories per sq. cm.	Item.	Gramme calories per sq. cm.
Light radiation from the sun and sun-lit sky actually absorbed by the black cotton soil surface.	740	Heat radiated by the soil surface during the day time.	680
Heat radiation from the sky during the day and at night.	654	Heat radiated by the soil surface during the night.	480
Heat conducted to the surface at night from the soil layers below.	222	Heat removed from the soil surface by the atmosphere by convective processes.	210
		Heat conducted from the surface to the lower layers of the soil during the day time.	240
Total Gain ..	1616	Total Loss ..	1610

3. SOIL TEMPERATURE EXPERIMENTS.

In a recent note[11] we outlined a simple scheme for conducting experiments on soil temperatures. As mentioned in the previous section the temperatures attained by different layers of a soil, when its surface is exposed to solar radiation and to the other contemporary meteorological phenomena, will depend to a large extent upon the colour and cover of the surface and the chemical and physical composition of the different layers below the surface. For a preliminary and a comparative study of the behaviour of different typical soils with respect to soil temperatures, the variation due to climatic differences from place to place was eliminated by bringing sufficiently large amounts of the selected soils to one place of observation, viz. the observatory at Poona. The experiments were made in distinct stages as follows :—

I. The physical and chemical properties of the soil were kept identical by working with plots of the undisturbed local soil ; the plots measured $6\frac{1}{2}$ ft. by $3\frac{1}{2}$ ft. each and similar sets of thermometers were installed at the different depths. The site of the soil temperature plots and their arrangement will be clear from the photograph reproduced here (Fig. 1).

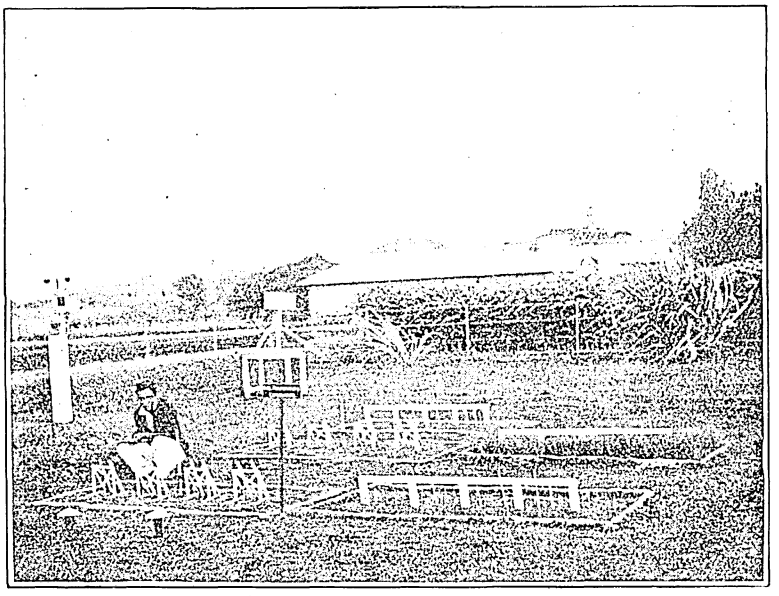


FIG. 1. Soil Temperature Plots.

The type of thermometer used (manufactured by R. Fuess) is shown in Fig. 2. It is sensitive and the bend near the bulb makes it easy to fix the bulb at a definite depth ; it is also convenient to take the temperature readings from the stem. Comparative observations were taken to verify that the temperatures at similar depths were similar. One of the plots was kept as a permanent ' control ' plot and each of the remaining plots covered with thin layers of the different typical soils and of substances like chalk and charcoal powder. The simultaneous observations were then continued in order to record the influence of the ' cover ' on the temperatures of the soil layers below.

Along with these experiments it was also arranged to measure the effects of wetting just the surface of the soil and of growing a short crop on the soil temperatures.

II. Having ascertained the effect of the ' cover ', the effect of varying both the physical and chemical composition of the soil was studied by using blocks of different soils of sufficient depth. The soil blocks were kept with their natural surfaces exposed in the first part of the experiment and, after comparative observations had proceeded for a sufficiently long time, all except the local ' control ' plot were covered with a thin layer of the local black cotton soil so as to eliminate the influence of the surface colour and retain only the variations due to the interior of the blocks of different soils.

Although the several series of comparative observations have been recorded at several fixed hours daily we shall take up only the data recorded

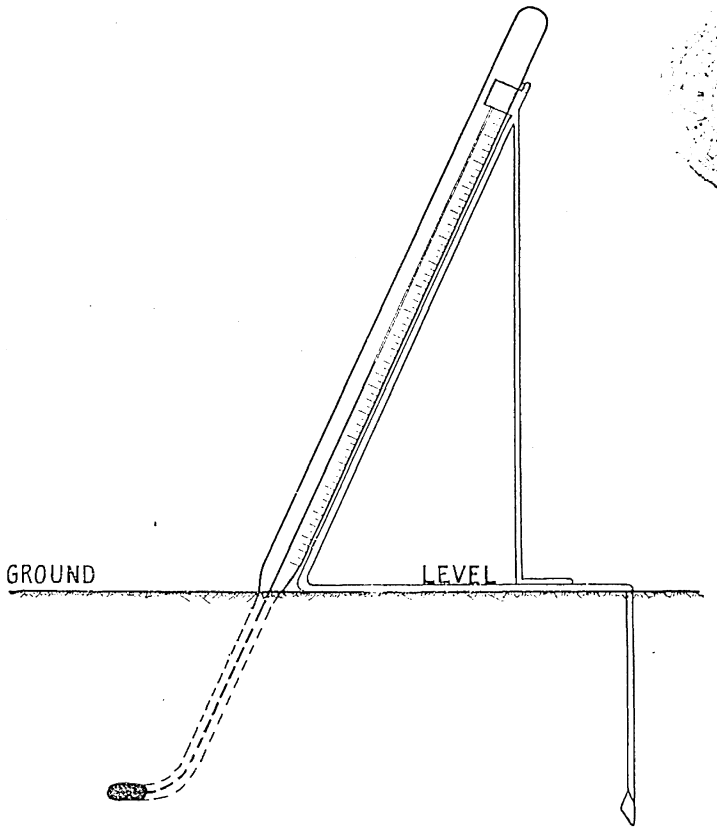


FIG. 2. Fuess Soil Thermometer.

at 6 A.M. and 2 P.M. which represent the extreme conditions of the day and select the more interesting cases for discussion in the present paper.

I. *Experiments on the effect of soil cover.*

(*a*) The effect of covering the local black cotton soil with very thin layers of the following substances was studied.

1. Chalk or boric powder .. (white)
2. Trivandrum sea sand .. (white)
3. Soil from Sakrand in Sind .. (ash coloured)
4. Soil from Lyallpur .. .. (light brown)
5. Soil from Pusa .. .. (ash coloured)
6. Soil from Mekran .. .. (Yellowish brown)
7. Soil from Bangalore .. .. (red)
8. Soil from Sholapur .. .. (black)
9. Charcoal powder .. .. (black)

TABLE 2.

Mean soil temperatures at different depths during the week 30th April to 6th May, 1935.

Depth in centimetres.	Morning 0600 Hours. Soil Temperatures °C.					Afternoon 1400 Hours. Soil Temperatures °C.				
	Control.	Boric Powder.	Pusa soil.	Lyallpur soil.	Sholapur soil.	Control.	Boric Powder.	Pusa soil.	Lyallpur soil.	Sholapur soil.
0	19·3	19·1	19·2	19·7	20·3	62·5	48·3	58·0	58·6	64·6
2	24·6	23·3	25·1	23·8	25·4	49·9	41·3	47·3	48·6	50·4
5	26·8	26·1	26·8	26·9	27·9	45·0	38·2	42·9	43·2	45·3
10	31·0	29·5	30·8	30·7	31·6	37·7	34·5	36·7	36·9	38·1
20	33·3	31·4	33·0	32·4	33·4	33·0	31·2	32·6	32·6	33·2

TABLE 3.

Mean soil temperatures at different depths during the week 24th to 28th January, 1935.

Depth in centimetres.	Morning 0600 Hours. Soil Temperatures °C.					Afternoon 1400 Hours. Soil Temperatures °C.				
	Control.	Trivandrum white sand.	Mekran soil.	Sakrand soil.	Bangalore soil.	Control.	Trivandrum white sand.	Mekran soil.	Sakrand soil.	Bangalore soil.
0	13·6	14·2	13·6	13·2	13·7	50·8	39·4	45·6	45·7	47·3
2	17·4	16·4	16·7	16·7	17·0	41·0	35·2	38·8	38·4	39·2
5	19·9	19·2	19·5	19·8	19·8	34·5	29·5	32·4	32·2	32·9
10	22·9	21·8	22·0	22·2	22·3	27·0	24·7	26·0	25·9	26·0
15	24·3	23·3	23·5	23·4	23·6	24·7	23·4	23·8	23·8	24·0
20	24·5	23·8	24·1	23·9	24·1	24·0	23·3	23·6	23·7	23·8

Table 2 gives the mean soil temperatures at 0, 2, 5, 10, 15, and 20 cm. depths for the week beginning with the 30th April, 1935 on the morning of which date covers* of boric powder, Pusa soil, Lyallpur soil and Sholapur soil were applied to the respective plots. The mean weekly temperatures are given both for 6 A.M. and 2 P.M.

During the weeks prior to 30th April, when the soil plots were all similar, the temperatures of all the plots agreed at all depths, both in the morning as well as in the afternoon. After the application of the different covers, however, the temperatures begin to deviate from those of the control plot, in proportion to the albedo of the respective substances used. These differences are relatively small in the morning but in the afternoon they show up very conspicuously. Thus the effect of boric powder is *to lower the temperature* at 2 P.M. by 14·2° C, 8·6° C, 6·8° C, 3·2° C and 1·8° C at depths of 0, 2, 5, 10 and 20 cm. respectively. The Sholapur soil which is slightly darker than the Poona soil has, on the other hand, caused a slight rise in temperature of the order of 2·1° C, 0·5° C, 0·3° C, 0·4° C and 0·2° C at depths of 0, 2, 5, 10 and 20 cm. respectively.

Table 3 gives the mean temperatures during the week beginning with the 24th January on the morning of which date covers of Trivandrum sand and soils from Mekran, Sakrand and Bangalore respectively were applied to the experimental plots. The effect of all these substances is to depress the soil temperatures in the afternoon by varying extents. Trivandrum white sand has the maximum cooling effect of 11·4° C, 5·8° C, 5·0° C, 2·3° C, 1·3° C and 0·7° C at depths of 0, 2, 5, 10 15 and 20 cm. respectively. The soils from Mekran and Sakrand also produce a similar but less conspicuous cooling in the afternoon, whereas the red soil from Bangalore has the least cooling effect, i.e. only 3·5° C, 1·8° C, 1·6° C, 1·0° C, 0·7° C and 0·2° C at depths of 0, 2, 5, 10, 15 and 20 cm.

Table 4 gives the mean weekly soil temperatures in two plots *A* and *B*, where *A* is the usual standard control plot. The experiment was begun on 25th December, 1933, and lasted upto 1st February, 1934. The different periods designated 1, 2, 3, 4, 5 and 6 in the table were as follows :—

Week No.	*Dates.*
1	25-12-33 to 31-12-33
2	1-1-34 to 7-1-34
3	8-1-34 to 14-1-34
4	15-1-34 to 21-1-34
5	22-1-34 to 28-1-34
6	29-1-34 to 1-2-34

During the first week when the plots were kept similar the soil temperatures at different depths were also similar both in the morning as well as in the afternoon.

* The covers were just thick enough to hide the surface of the local soil (about 2 mm.).

TABLE 4.

Mean weekly soil temperatures in the morning and afternoon at different depths during the period 25-12-33 *to* 1-2-34 *showing the effect of covering the plot B with a thin layer of chalk powder on the morning of* 1-1-34 (*beginning of week No.* 2) *and of removing this cover on* 21-1-34 (*end of week No.* 4).

Morning 6 *A.M.*

Week No.	1		2		3		4		5		6	
Depth cm.	A	B	A	B	A	B	A	B	A	B	A	B
0	11·0	11·1	14·7	14·3	12·1	10·9	9·6	8·4	11·9	11·6	12·7	12·6
5	17·2	17·1	19·5	18·1	18·9	16·4	17·1	14·7	17·6	17·3	19·2	18·7
10	20·5	20·3	21·7	20·1	21·8	19·3	20·5	17·5	20·8	20·1	22·2	21·9
15	22·6	22·5	23·2	21·7	23·6	21·0	22·4	19·6	22·4	21·9	23·9	23·7
20	23·6	23·4	23·7	22·4	24·3	22·0	23·4	20·6	23·2	22·6	24·5	24·5
30	24·4	24·4	24·3	23·2	24·8	22·9	24·1	21·8	23·7	23·2	25·0	25·0
50	24·9	24·8	24·6	24·2	25·0	24·1	24·5	23·3	24·0	23·4	24·7	24·6

Afternoon 2 *P.M.*

Week No.	1		2		3		4		5		6	
Depth cm.	A	B	A	B	A	B	A	B	A	B	A	B
0	44·9	44·9	42·1	31·3	50·1	31·9	50·7	36·7	49·6	48·8	46·1	45·2
5	30·1	30·3	28·7	24·0	31·3	24·1	31·1	23·6	31·8	31·3	31·6	32·0
10	24·9	24·9	24·8	21·8	26·1	21·4	24·8	20·1	25·0	24·6	26·6	26·7
15	23·0	22·9	23·3	21·5	24·0	20·9	22·7	19·5	23·0	22·3	24·8	24·8
20	22·8	22·9	23·1	21·9	23·7	21·4	22·5	20·0	22·6	22·0	24·3	24·4
30	24·1	23·9	24·1	23·1	24·7	22·8	23·7	21·6	23·4	22·7	24·8	24·7
50	25·2	25·1	24·8	24·3	25·3	24·3	24·7	23·6	24·2	23·7	25·0	24·9

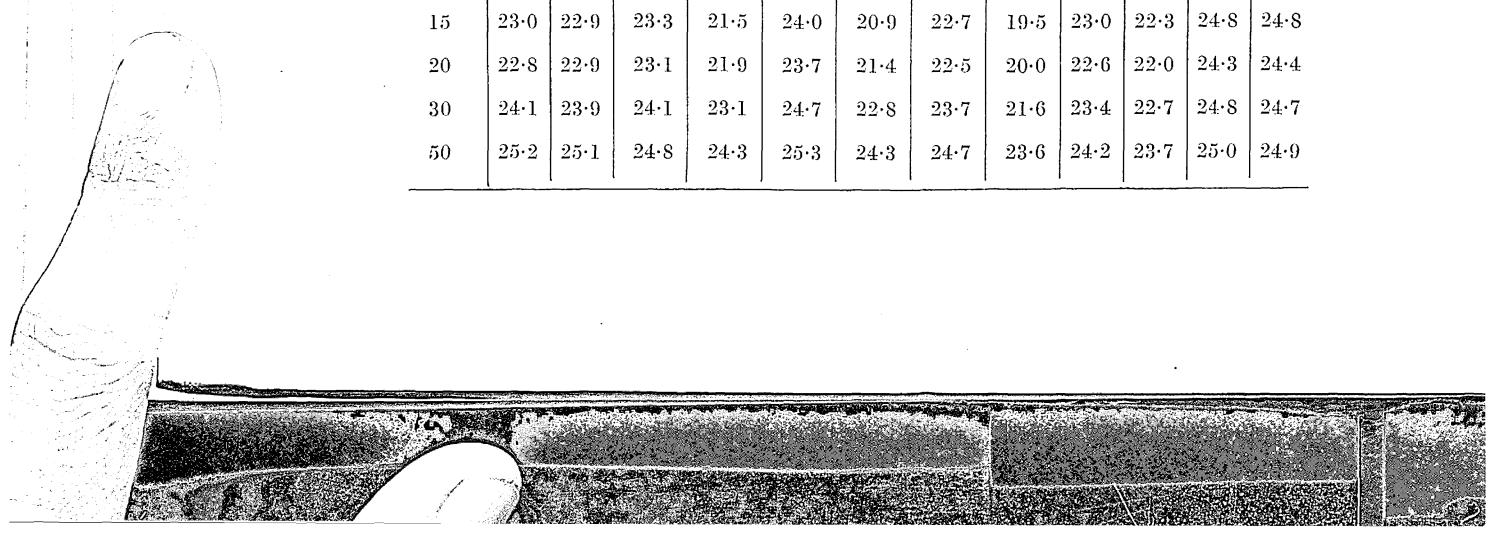


TABLE 5.

Soil temperatures in two plots A (control) and B (experimental) during the period 3rd to 6th May, 1934, showing the effect of wetting the surface of the plot B on the morning of 3-5-34.

Morning 6 *A.M.*

Dates.	3-5-34		4-5-34		5-5-34		6-5-34	
Depth cm.	A	B	A	B	A	B	A	B
0	22·8	23·8	21·3	20·2	19·2	18·5	16·6	17·1
0·5	24·0	24·7	22·4	20·6	20·5	19·6	18·5	18·0
2	27·0	27·0	25·2	23·0	24·0	23·0	22·0	21·5
5	29·1	29·4	28·0	25·9	27·3	26·0	25·8	25·2
10	31·6	32·0	30·4	28·7	30·6	29·8	29·6	29·5
15	33·2	33·2	32·7	30·2	32·5	31·3	32·1	31·0
20	33·6	33·8	33·6	32·0	33·4	32·0	33·1	32·1
30	33·8	33·8	33·9	32·9	33·8	32·8	33·6	32·6

Afternoon 2 *P.M.*

Dates.	3-5-34		4-5-34		5-5-34		6-5-34	
Depth cm.	A	B	A	B	A	B	A	B
0	66·4	55·3	63·3	59·8	62·1	60·0	64·5	63·5
0·5	61·0	46·2	57·8	53·4	56·5	54·1	59·8	57·8
2	50·8	40·1	48·0	42·1	46·4	43·3	49·2	46·5
5	41·6	37·2	39·8	36·1	37·8	37·5	39·8	39·6
10	36·9	33·8	36·0	33·3	35·3	33·2	35·6	33·6
15	34·4	32·4	33·8	31·7	33·5	31·6	33·0	31·5
20	33·3	32·9	33·2	32·0	33·0	32·2	32·4	31·9
30	33·5	33·3	33·6	32·6	33·4	32·5	33·1	32·4

At the beginning of the 2nd week, i.e. on the morning of 1st January, 1934, the plot *B* was covered with a thin layer of chalk. During the second week the temperatures in the plot *B* began falling and by the 3rd week the differences became quite marked in the afternoon, being as much as 18·2° C, 7·2° C, 4·7° C, 3·1° C, 2·3° C, 1·9° C and 1·0° C at depths of 0, 5, 10, 15, 20, 30 and 50 cm. respectively. During the 4th week these differences still persisted. At the end of this week the chalk cover was removed from the plot *B*. The effect of this was to enable the plot *B* rapidly to warm up during the fifth week and ultimately to assume temperatures similar to those in the control plot. From the daily observations during this period it is clear that the effect of a change of cover takes some time to become fully established.

(b) *Effect of wetting just the surface of the soil.*

After the soil temperatures in the two plots *A* (control) and *B* (experimental) had become more or less similar for a number of days the surface of the plot *B* was wetted uniformly with water equivalent to 0·5 ″ of rain. From Table 5 it will be seen that the effect of wetting plot *B* on the morning of the 3rd May has been to depress the afternoon soil temperatures in that plot by

TABLE 6.

Morning and afternoon soil temperatures on 17-11-35 *in three plots at different depths showing the effect of a plant cover.*

Depth in centimetres	Morning 0600 Hours.			Afternoon 1400 Hours.		
	Soil Temperatures °C.			Soil Temperatures °C.		
	Control. A	Plot with plant cover.* B	Bare plot watered to the same extent as the one with plant cover. C	Control. A	Plot with plant cover.* B	Bare plot watered to the same extent as the one with plant cover. C
0	8·4	10·5	9·2	53·4	26·6	39·7
2	16·2	15·0	11·8	37·0	26·5	31·5
5	16·7	16·8	13·7	31·2	25·2	26·9
10	21·0	20·5	18·2	25·5	22·0	21·6
15	21·5	21·9	20·9	23·7	21·6	21·2
20	24·5	22·3	22·5	23·9	21·7	21·8

* ' Aleev ' growth 20 cm. high.

11·1° C, 14·8° C, 10·7° C, 4·4° C, 3·1° C, 2·0° C, 0·4° C and 0·2° C at depths of 0, 0·5, 2, 5, 10, 15, 20 and 30 cm. respectively. The recovery from the effect of wetting is perceptible even on the next day but it is only after the 6th May that the temperatures in the two plots become more or less equal.

(c) *Effect of Plant Cover.*

The soil temperatures at 6 A.M. and 2 P.M. on the 17th November, 1935, in the following three plots, are given in Table 6.

(A) Bare and dry control plot.

(B) Plot covered with a crop of ' Aleev ' 20 cm. high.

(C) Bare plot receiving the same amount of water as the ' Aleev ' plot during its growing period.

The morning soil temperatures in plot *B* in the layers near the surface are warmer than in plots *A* or *C*. Immediately below the surface the plot *C* is cooler than both *A* and *B*.

In the afternoon, however, plot *B* is cooler than the control plot *A* by as much as 26·8° C, 10·5° C, 6·0° C, 3·5° C, 2·1° C, and 2·2° C at depths of 0, 2, 5, 10, 15 and 20 cm. respectively. The plot *C* is warmer than plot *B* but cooler than the control plot.

The effect of a covering of vegetation in keeping down the afternoon temperatures in the upper layers of the soil is well illustrated by these data.

II. *Experiments with soil blocks.*

These experiments were started with soils from Trivandrum (sand), Sakrand and Bangalore. Pits 6½ ft. by 3½ ft. and 1 ft. or 30 cm. deep were dug, keeping the bottom of the pits quite horizontal. The vertical sides of the pits were supported with a lining of brick and cemented up. The lining of cement helps also to prevent the seepage of water from the sides during rainy weather. These pits were carefully packed with the soils referred to above, the top surfaces of the different soil blocks so obtained being kept horizontal and at the same level as that of the ground in the neighbourhood. The standard sets of soil thermometers were then installed in these soil blocks and compared with those in the permanent control plot.

The natural surfaces of the respective soil blocks were kept undisturbed during the first part of the experiment. Table 7 gives the mean soil temperatures during the week ending with the 10th May, 1936. The temperatures in the upper layers of the white Trivandrum sand are lower than those in the control both in the morning and in the afternoon. The surface temperature in the Sakrand soil is lower than those in the control but higher than in the Trivandrum sand both in the morning and in the afternoon ; but below 15 cm. the temperatures are slightly warmer than in the other two soils.

From Table 8 it will be seen that when the surface colours were equalised on the morning of the 11th May by covering the Trivandrum sand and the

TABLE 7.

Mean soil temperatures during the week ending 10th May, 1936, in Poona soil (control) and in Trivandrum sand and Sakrand soil, each being exposed with its natural colour undisturbed.

Depth in centimetres.	Morning 0600 Hours.			Afternoon 1400 Hours.		
	Soil Temperature °C.			Soil Temperature °C.		
	Control.	Trivandrum sand.	Sakrand soil.	Control.	Trivandrum sand.	Sakrand soil.
0	21·2	18·1	20·3	69·2	58·4	64·3
2	27·6	24·3	24·7	53·3	53·0	55·4
5	28·0	26·7	27·5	48·1	45·7	48·5
10	31·9	29·5	31·5	38·0	39·6	40·1
15	33·6	31·9	..	34·3	35·1	..
20	33·6	33·5	34·7	33·2	33·2	34·1
30	33·6	33·2	34·2	33·5	33·1	34·1

TABLE 8.

Mean soil temperatures during the week ending 17th May, 1936, in Poona soil and in Trivandrum sand and Sakrand soil, the last two soils being covered with a thin layer of Poona soil so as to equalise the colours of the surfaces.

Depth in centimetres.	Morning 0600 Hours.			Afternoon 1400 Hours.		
	Soil Temperatures °C.			Soil Temperatures °C.		
	Control.	Trivandrum sand.	Sakrand soil.	Control.	Trivandrum sand.	Sakrand soil.
0	22·5	19·7	22·6	70·0	69·1	67·1
2	28·3	25·8	26·7	53·0	60·9	57·5
5	28·8	28·7	29·4	47·4	51·8	50·8
10	32·8	31·7	32·7	38·2	44·0	42·2
15	34·2	34·2	..	34·7	38·4	..
20	34·0	35·4	36·0	33·6	35·3	35·4
30	34·0	34·5	35·2	33·7	34·2	34·9

Sakrand soil with a thin (2 mm.) layer of Poona soil the temperatures in the sand and Sakrand soil began to increase rapidly and approach those in the control. Sand being a poor conductor of heat, the afternoon temperature just below the surface is higher in it than in either the control or the Sakrand soil; for the same reason the morning temperature in the upper-most layers of the sand are lower than those in the other two cases in spite of the colours having been equalised.

4. Conclusion.

The experiments outlined above suggest the possibility of controlling soil temperatures by suitable surface treatment.

The junior author of this note is discussing these results in a fuller report under preparation. The exact rôle played by thermal conductivity and the interrelations between the amplitudes and phases of the diurnal waves of temperature at different depths will be fully explained there. Further experiments on the above lines are being continued.

The influence of different cultural treatments on the temperature of the soil below will also be investigated during the next clear season.

Our best thanks are due to the Imperial Council of Agricultural Research which, by inaugurating work in India on the subject of Agricultural Meteorology, has made the present investigations possible.

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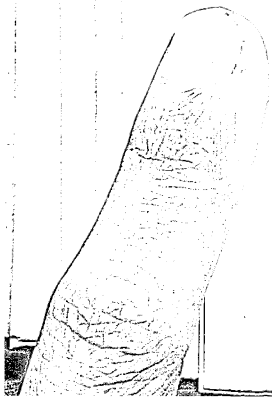
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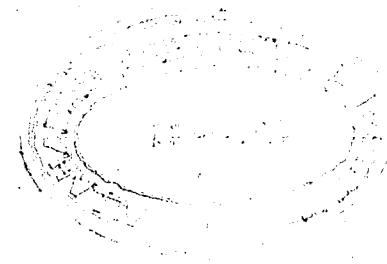
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The Diurnal Variation of Moisture in the Soil during the Clear Season.

EXPERIMENTS on soil moisture conducted by the Agricultural Meteorology Branch at Poona during the last two clear seasons (October-April) have shown[1] that during the clear season at Poona, when the surface layer of the soil is so far desiccated as to contain only hygroscopic moisture, the evaporation from the soil during the day is followed by absorption of moisture from the atmosphere during night by the soil. Under these conditions the soil does not undergo any material loss of moisture from day to day. The evaporation from and absorption by the soil result also in a variation of moisture in the air layers near the ground. These phenomena are therefore of particular interest to those engaged in a study of micro-climates and the meteorology of the air layers near the ground. This aspect of the subject has also been discussed in the above-mentioned paper.

In a later communication[2] we reported that samples of different soils kept in small vessels show characteristic intensities of "evaporation" and "absorption" when exposed to identical meteorological conditions. These observations have been confirmed by further experiments with a variety of soils during the last clear season.

The amplitude of the diurnal variation in the moisture contents of different soils expressed as a ratio of that of the Poona soil are given below :—

Name of Soil	Diurnal variation of moisture content expressed in terms of Poona Soil (=1).
Poona black cotton soil ..	1·00
Dharwar black cotton soil ..	1·10
Sholapur black soil ..	1·04
Hagari ..	0·86
Red Laterite ..	0·81
Ranchi ..	0·65
Jhelum ..	0·44
Bangalore ..	0·29
Pusa (alluvial) ..	0·20
Lyallpur (alluvial) ..	0·21
Sakrand (alluvial) ..	0·19
Quartz powder ..	0·00

The above table shows that the black cotton soils undergo the maximum diurnal variation of moisture content owing to the loss of water by evaporation during day and gain by absorption from the air during night. The alluvial soils from the Indo-Gangetic as well as the Sindh areas experience only a fifth of the diurnal variation shown by the black cotton soils. Quartz powder appears at the bottom of the list with no variation. It is indeed remarkable that soils of the same type from places as far from each other as Pusa, Lyallpur and Sakrand have the same moisture variation index. A similar remark applies to the black cotton soils as well.

The epoch of *minimum soil moisture* content occurs a few hours after the epoch of maximum soil surface temperature (which occurs at noon), and coincides with the epoch of "maximum air temperature and minimum percentage humidity". The epoch of *maximum soil moisture* content coincides with the epoch of "minimum air temperature and maximum percentage humidity".

The hourly variation of the moisture content of the Poona soil at different depths has also been studied by taking actual hourly samples from the field and determining their moisture contents. It is seen that the diurnal variation is maximum at the surface and decreases very rapidly with depth, being practically insignificant even at a depth of 1" below the surface.

The mechanical and chemical analysis of the soils used by us, the study of their adsorptive properties under laboratory conditions as well as experiments on their heats of adsorption and wetting are in progress.

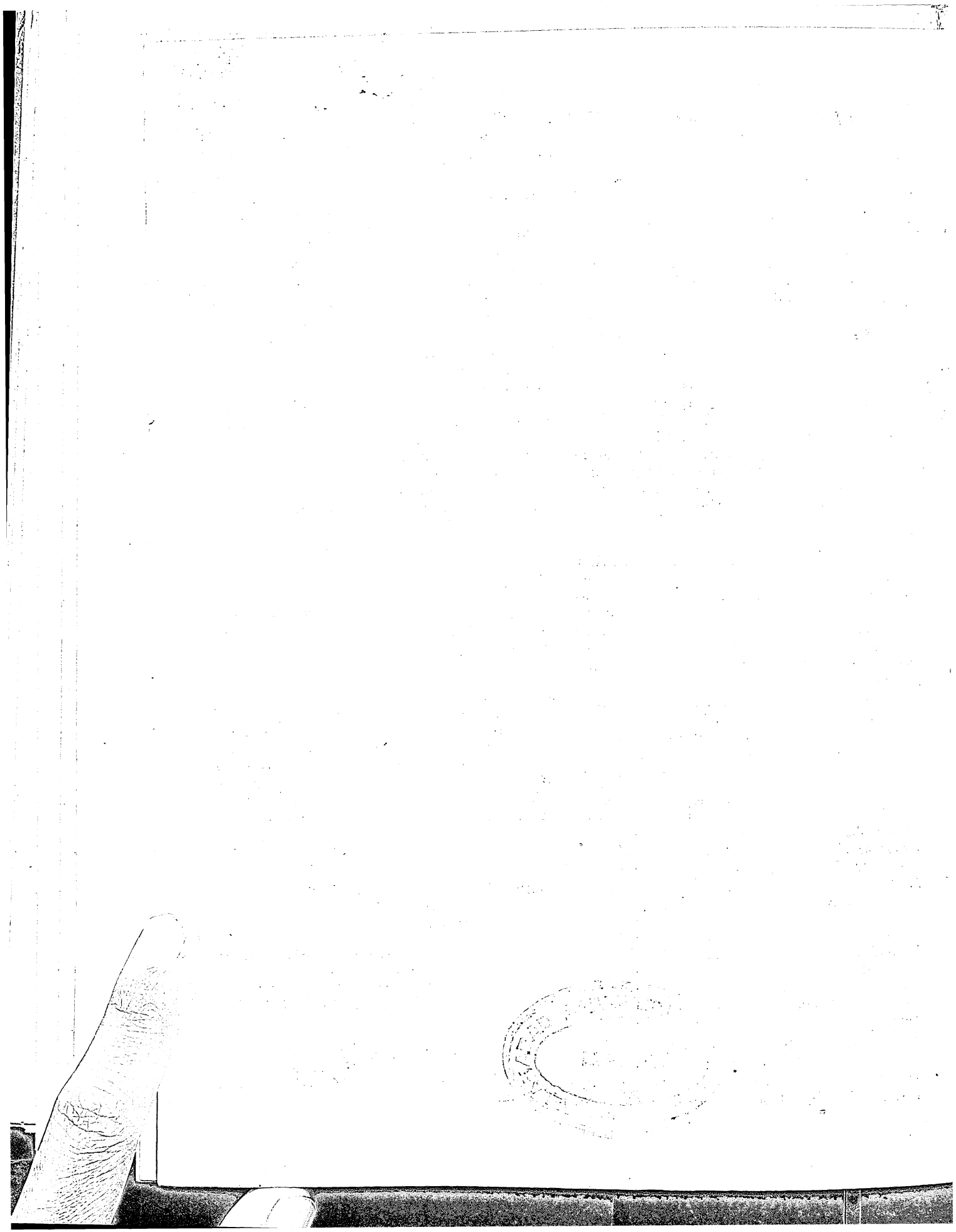
The results briefly outlined here are being discussed more fully in a forthcoming paper.

L. A. RAMDAS.
M. S. KATTI.

Indian Meteorological Department,
Poona,
June 12, 1935.

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Moisture Variation Indices of Soils in Relation to their other Physical Properties.*

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IN two recent papers[1,2] it was shown that during the clear season when the surface soil contains only hygroscopic moisture, there is a regular diurnal exchange of moisture between the soil and the air. Later,[3] it was observed that this variation of moisture content in the soil is a definite characteristic or "index" of that soil. It is interesting to study the "moisture-variation-index" in relation to other important physical properties of the soil (see Fig.).

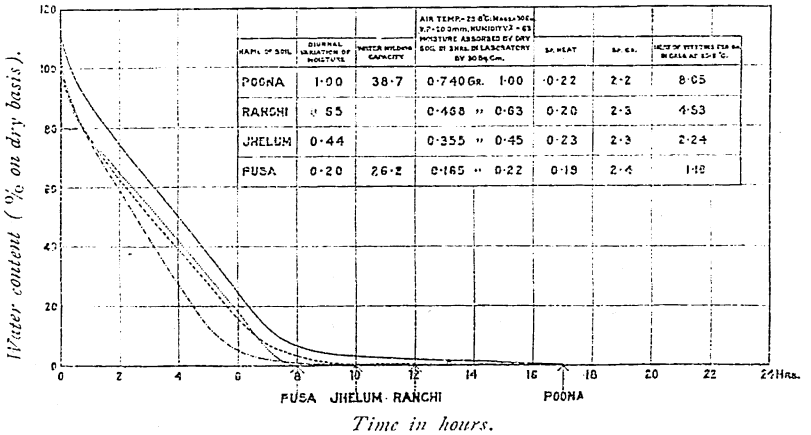
The sequence of the moisture variation indices of different soils as observed in the open is practically the same as that of their power to absorb water vapour when exposed under known conditions of temperature and humidity in the laboratory. The water-holding capacities of a few soils (expressed on air-dry basis) are given below :—

Soil	Water-holding capacity
Poona	38·7 %
Sholapur	40·9 ,,
Hagari	30·9 ,,
Bangalore	24·0 ,,
Pusa	26·2 ,,
Lyallpur	22·8 ,,

The black cotton group of soils is able to retain 15% more of water than the alluvial group.

The values of the heat of wetting at 25·9° C. for different soils run parallel to those of moisture-variation-index, being large for the black cotton soils and small for the alluvial soils.

In determining the moisture content of a soil, the sample is usually kept in the steam oven "till the weight becomes constant". An exact study of the rate of drying in a steam oven is very instructive. The weight-time curves (see Fig.) for four typical soils starting with about 100% water (on dry basis) not only show the time for complete drying but also the rate of drying at different moisture contents. The times taken by different soils for attaining a steady minimum weight at 100° C. are in the same order as their moisture-variation-indices.



Name of Soil	Diurnal variation of moisture	Water holding capacity	Moisture absorbed by dry soil by 24 hrs. in laboratory by 30·5 g Cm.	Sp. heat	Sp. gr.	Heat of wetting for 1 gm. soils at 15·9 °C.
POONA	1·00	38·7	0·740 Gr. 1·00	0·22	2·2	8·05
RANCHI	0·55		0·468 ,, 0·63	0·20	2·3	4·53
JHELUM	0·44		0·355 ,, 0·45	0·23	2·3	2·24
PUSA	0·20	26·2	0·165 ,, 0·22	0·19	2·4	1·12

Time in hours.

The similarity in the behaviour of a number of physical properties of different soils to their moisture-variation-indices is striking.

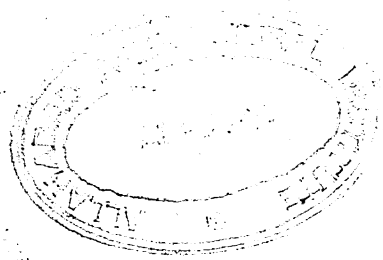
The above work was done under the guidance of Dr. L. A. Ramdas, Agricultural Meteorologist, Poona.

* Presented at the Colloquium, Meteorological Office, Poona, on 26-11-1935.

[1] Ramdas, L. A., and Katti, M. S., *Indian J. Agric. Sci.*, 1934, **4**, 923-37.

[2] Ramdas, L. A., and Katti, M. S., *Curr. Sci.*, 1934, **3**, 24-25.

[3] Ramdas L. A., and Katti, M. S., *Curr. Sci.*, 1935, **3**, 612-13.



Reprinted from "Current Science," Vol. II, No. 11, May 1934, pages 445-447.

Micro-Climatology.*

By L. A. Ramdas,
Agricultural Meteorologist, Poona.

Introduction.

In meteorology we have been concerned in the past with the prediction of weather over comparatively large tracts of country. The large-scale phenomena in the earth's atmosphere extend up to several kilometres above the ground and contribute to what may be called "macro-meteorology". It is usual to consider the surface of the ground and the adjacent air layers upto about 2 metres above ground as disturbing factors. When the meteorologist, however, turns his attention to problems relating to agriculture he finds that it is just this disturbance zone which assumes great importance.

Three years ago, the speaker, in collaboration with a few other workers, undertook a detailed investigation of phenomena taking place in the air layers near the ground.[1, 2, 3] With the creation of the Agricultural Meteorology Branch towards the close of 1932, our studies received a new orientation and the programme of work has included, among other items, also a study of the variation of the micro-climate in different environments, *e.g.*, inside and outside different crops.

In Europe Schmidt, Geiger and others have been studying the micro-climate in temperate latitudes during the past few years and have made numerous important contributions to this new subject.[4]

The International Commission on Agricultural Meteorology at its last meeting at Munich[5] (September 1932) passed several important resolutions emphasising the importance of "micro-climatology" and its investigation in all countries. Similar resolutions were also passed at the Conference of Empire Meteorologists,[6] London, 1929.

The aims of "micro-climatology" are (1) to investigate the physical laws underlying the deviations of "micro-climate" from "macro-climate"; for, a knowledge of these laws is essential for getting a fresh insight into atmospheric phenomena, and (2) to apply the theoretical results to practical ends, *e.g.*, a knowledge of the regular deviations would enable one to predict possible conditions in the hitherto unsurveyed regions with some confidence. In the tropics, owing to the intensive insolation, the "macro-climate" may be expected to be more profoundly modified by variations in the environment than in higher latitudes.

Some of the important aspects of this new subject may now be summarised very briefly. The influence of orography and crops, problems relating to experimental technique, "effective rainfall", etc., will be discussed on a future occasion.

Role of Solar Radiation.

Most variations of atmospheric conditions may be traced ultimately to (*a*) variations in the intensity of solar radiation received at the earth's surface, and (*b*) variations in the disposal of the thermal energy derived by the earth's surface from solar radiation. The first factor varies with season and latitude. The second factor depends on (i) the exchange of heat between the surface of the ground and the layers of the soil which are affected by the diurnal variation of temperature, *i.e.*, the "conduction process", (ii) the exchange of heat between the surface of the ground and the air layers in contact with it or, in other words, the "convective process", (iii) the exchange of thermal energy between the ground surface and the atmosphere by radiation processes, which again are modified by the water vapour and carbon-dioxide content of the atmosphere, and (iv) the heat lost or gained by the earth's surface due to "evaporation" or "condensation" of water at the surface.

Detailed measurements of these complex factors which control what may be called the "thermal balance" at the earth's surface are necessary for a proper understanding of the phenomena taking place in the air layers near the ground and in the first few feet of the soil below. Investigations on these lines are in progress at Poona.

Surface Conditions.

The colour of the soil determines the absorbing and the radiating power of the surface. A black surface absorbs most of the incident solar radiation whereas a white surface reflects a considerable fraction of it and is a poor absorber. Recent experiments at Poona show that a very thin coating of chalk over the black cotton soil depresses the maximum temperature by about 15° C. at the surface, 5° C. at a depth of 5 cms., and 3° C. at a depth of 10 cms. At depths of 5 and 10 cms. the minimum temperature also is lowered by about 2° C. These effects penetrate further downwards with rapidly decreasing intensity. The changes take a few days to be fully developed: on removing the chalk the normal conditions are restored gradually and the temperatures become similar to those under the untreated soil only after a few days.

Similarly, even a very thin coating of wet soil at the surface decreases the amount of heat conducted downwards because part of the solar energy received by day is utilized for evaporation. The effects of soil covers of different colours, of a crop cover, and of wetting the surface of the

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* Report of a lecture on "Micro-Climatology" at the Colloquium, Meteorological Office, Poona, on 10th April 1934.

[1] "Theory of extremely high lapse-rates of temperature very near the ground," by S. L. Malurkar and L. A. Ramdas, *Indian Journal of Physics*, VI, Part 6, p. 495.

[2] "Surface convection and variation of temperature near a hot surface," by L. A. Ramdas and S. L. Malurkar, *Indian Journal of Physics*, VII, Part 1, page 1.

[3] "The vertical distribution of air temperature near the ground during night," by L. A. Ramdas and S. Atmanathan, *Gerlands Beitrage Zur Geophysik*, 37, pages 116-17, 1932.

[4] *Handbuch der klimatologie*, Band I, Teil D, "Mikroklima and Pflanzenklima" Von Dr. Rudolph Geiger (1930). Contains an excellent bibliography of micro-climatological papers upto 1930.

[5] Proceedings of the Commission on Agricultural Meteorology; Munich Meeting, publication No. 14, "Secretariat de L'organisation Meteorologique, International."

[6] Resolution No. XIII of the Conference of Empire Meteorologists 1929, Agricultural Section, Report (p. 11, paras 29, 30, 31 and 32).

ground, on soil temperatures at various depths are being investigated at Poona.

Soil Conductivity.

The thermal conductivity of the soil is an important factor in controlling the distribution of temperature in the soil as well as in the air above. It varies with different soils and, in the same soil, with the water content. As more and more water replaces the soil air (air is a poor conductor of heat) the conductivity increases; but the specific heat as well as the apparent density also increase so that, beyond a critical stage, the effect of further increasing the moisture content is to depress the thermal diffusivity.

In general, during the day hours a well-conducting soil transmits more heat into the interior, the surface remaining comparatively cool; at night the heat so stored up is returned rapidly to the surface to compensate the radiation loss. In such soils, the diurnal variation of temperature has a small amplitude. In badly conducting soils the heat energy gained by day mostly remains at the surface which becomes very hot and, at night, owing to the radiation loss not being compensated for by heat conducted from below, the surface attains a low temperature. This results in a large diurnal range of temperature in a shallow layer at the surface. The importance of the heat conductivity of the soil in relation to conditions during winter may easily be anticipated. Experiments show that a compact undisturbed soil has a warmer surface at night than one in which the soil has been turned up and loosened at the surface. Reports received from different places on damage to crops due to frost during the cold waves of January last show that crops irrigated prior to the onset of frost were less affected. A study of the thermal conductivity of different soils in varying degrees of packing and of moisture content is therefore of importance.

Convection Process and Radiation from the Earth's Surface and Adjacent air Layers.

During a clear day, the ground surface becomes very warm owing to the absorption of solar radiation; the air in contact with it is warmed up in its turn and is in unstable equilibrium with the denser and cooler air higher up. Consequently, there is a considerable vertical exchange of air mass in the shape of warm ascending currents of air and cool descending currents. This gives rise to the well-known "shimmering". The thermal structure of the "shimmering" layer has been investigated by Geiger[7] and recently ourselves by taking temperature observations with a sensitive thermo-couple set at quick intervals. The vertical interchange of air masses or what may be called "Surface Turbulence" is confined to the first few feet above ground. Above it, is the horizontal flow with its associated turbulence on a larger scale. The effective upward transfer of heat due to both the surface and the free air turbulence is minimum near the ground and, therefore, the ground and the air layers immediately in contact with it attain higher temperatures during afternoons than the air layers higher up.* Owing to the same reason the ground and the air layers near it cool more rapidly by night than the layers higher up. This results in a large diurnal range of temperature near the ground, the range rapidly decreasing with height. As may be expected in the higher latitudes, the frequency of frost is found to decrease with height. In tropical countries, however, owing to the fact that even during the night the ground is warmer than the cooling air above,[8] it may be expected that the height of maximum frost frequency will be a few inches above the ground. This is also supported by recent frost reports.

The conditions that prevail at night are equally interesting. Soon after sunset the ground and the air layers above it begin to cool rapidly by radiation. The air layers begin to stratify, *e.g.*, at Poona it is observed that the cooling of the air by radiation in winter is of the order of 10° C. per hour during the first half hour after sunset, the fall of temperature being large near the ground and decreasing with altitude. Occasionally, winds of local origin set in for short periods during the night; then the stratification is disturbed temporarily, the air layers get mixed up and there is a rise of temperature as a result. Towards the end of winter, the sea breeze sets in in the evenings and continues for a few hours during the night. During such nights the convection and the radiation processes act simultaneously and bring about a more gradual and less accentuated fall of temperature than during calm winter nights.

Wind Movements.

The complex thermal structure referred to in the above section has also its counterpart in the wind movements in the air layers near the ground. Simultaneous observations of wind velocity taken at various heights show considerable variations, the larger variations being associated with greater turbulence. It is found that there are three zones *viz.*, (*a*) one near the ground in which the surface disturbances predominate, (*b*) an intermediate layer in which the air is relatively quiet, and (*c*) the regions above where air movement is more or less horizontal and where the large-scale turbulence investigated by G. I. Taylor and others prevail. Schmidt's[9] observations also show that the surface turbulence increases with the roughness of the surface, *e.g.*, over a turnip field the variations in the wind movements are larger than over a bare plot.

Limits of Surface Climate.

The change from the surface to the climate of open space is not quite gradual. R. Geiger[10] quotes evidence to show that there is a level of transition at about 1½ to 2 metres above ground which would probably coincide with the quiet zone referred to in the previous section. In tropical regions it may be expected that, owing to the more intense insolation, the horizontal partition between the zone of vertical exchange and the zone of horizontal flow may be slightly higher up. Recent observations appear to show that this upper limit of the surface climate undergoes variation during the day, attaining a maximum height in the afternoon and coming down towards

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[7] Page D. 26 of publication (4) above.

* Temperature and humidity observations taken at several heights above ground, both above bare soil as well as inside a few representative crops at the epochs of maximum and minimum temperatures, are being discussed by the writer and others in a series of papers. Each crop is found to develop its own peculiar local climate, the deviations of which from the "open" depend upon the season and the growth of the crops.

[8] Ramdas and Atmanathan, *loc. cit.*

[9] Page D. 28 of (4).

[10] Page D. 31-34 of (4).

the ground in the evening and later during the night. Observations of the temperature distribution at short intervals of height and time after sunset indicate the rapid fall of this level which may be expected to coincide also with the level at which the nocturnal inversion of temperature begins. In short, the surface turbulence will not completely die away in the tropics even during winter nights owing to the greater warmth near the ground. In higher latitudes, owing to the weaker solar insolation, the surface turbulence will cease after sunset and the inversion of temperature may start at the ground surface itself.

The Water Vapour Content in the Atmosphere.

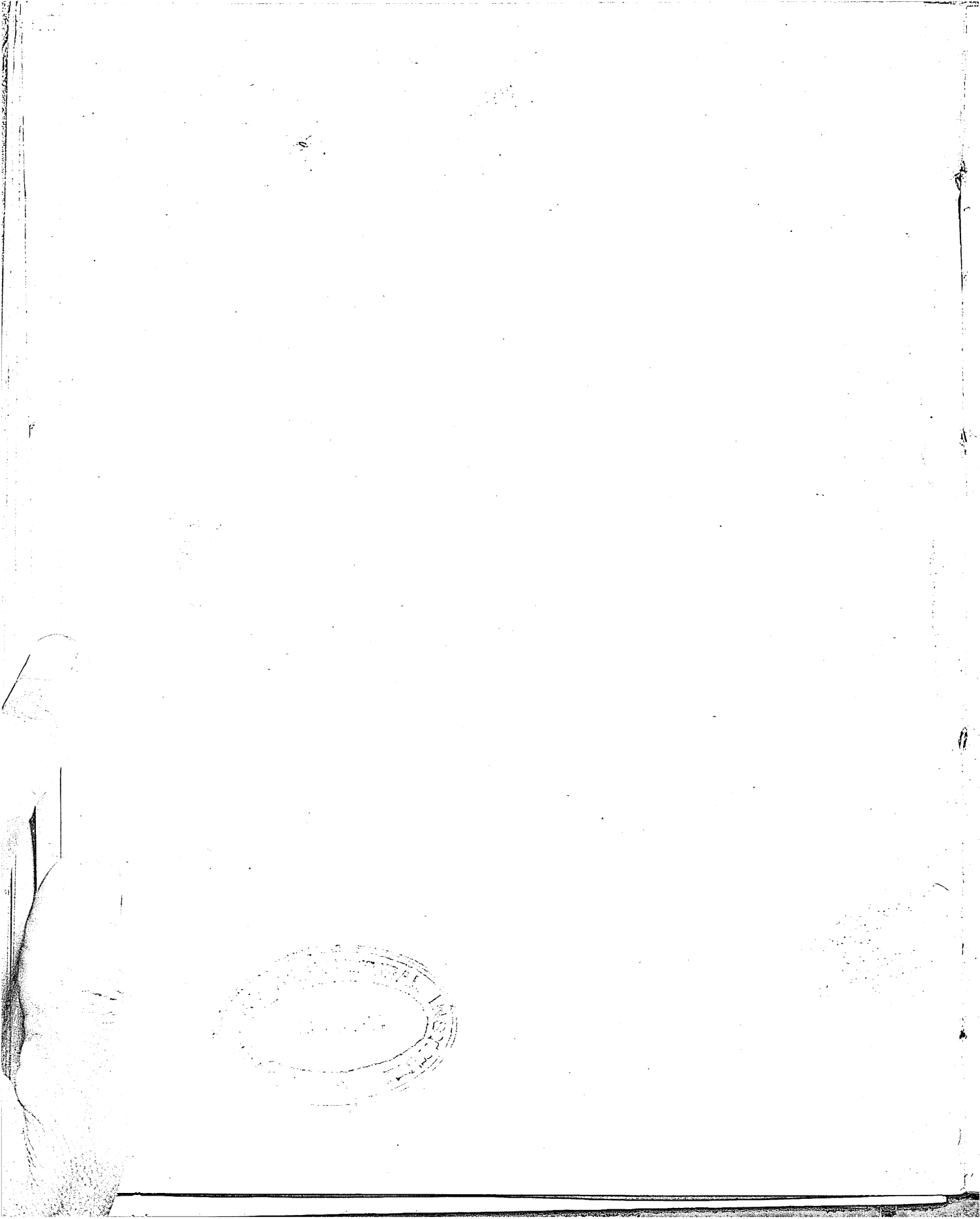
During all seasons of the year there is a considerable amount of evaporation of water from the soil surface. During the wet seasons it may be expected that the specific humidity in the air would be more or less constant with height above ground, with a tendency to be a maximum near the ground during periods of sunshine. At Poona, the above state of affairs prevail during the monsoon season, *i.e.*, June to September. During autumn, the upper layers of the soil rapidly desiccate and, by the time winter sets in, the loss by evaporation during day becomes smaller. It is still found that the usual decrease of vapour pressure with height persists even during this period. A surprising observation is that during night the above situation is reversed, *i.e.*, water vapour is minimum near the ground and rapidly increases with height. It was somewhat difficult to explain this at first sight, but, measurements of the loss of water from samples of soil exposed under natural conditions at the surface of the ground during the day showed that the loss is actually compensated by the absorption of moisture from the air by the same samples during the night. In other words, the soil which is intensively desiccated during the day acts as an absorber during the night thereby producing a minimum of vapour pressure near the ground. These results will be discussed more fully elsewhere.

Evaporation.

The evaporating power of the atmosphere is measured by the loss of water in small reservoirs with suitable measuring devices. As a meteorological element evaporation expresses the combined influence of temperature, humidity, sunshine, etc., as a single factor. Recent observations at Poona with a series of Piche's evaporimeters at various heights show that upto 4 ft. the evaporation increases with height even during the afternoon when the ground surface has the highest temperature. The effect of wind is thus seen to be more pronounced than that of the high temperatures near the ground. The study of the variations of evaporation in different environments at the same place, as well as the standardization of different types of evaporimeters are in progress.

Dew Fall.

When objects thermally insolated from the ground lose more heat than they gain from the air in their neighbourhood, their surfaces attain a lower temperature than the air. This results in condensation of water vapour if the lowering of temperature is sufficiently large. In many parts of India dew deposition during the night is very pronounced during clear weather. Exact measurements of dew deposition are not available at present, but qualitative observations at Poona made with collectors with bright surfaces exposed at various heights during last winter show that dew deposition starts from a height of 6″ to 1 ft. above bare ground and increases with height.



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THE CONVECTION AND VARIATION OF TEMPERATURE NEAR A HOT SURFACE.

Part II. Applications of Interferometry to the Measurements of Temperatures and Temperature Gradients Very Close to a Hot Surface.

By M. K. Paranjpe, B.Sc.
(*From the Meteorological Office, Poona.*)

Received November 11, 1936.
(Communicated by Dr. L. A. Ramdas, M.A., Ph.D.)

1. *Introduction.*

In Part I of this series[1] a discussion of the dust-free layer or clear space in the neighbourhood of a hot surface was made in the light of a series of experiments with an air cell consisting of a hot surface above and a cold surface below it. It was shown that when these two surfaces were 4 mm. or less apart from each other particles of smoke were repelled from the hot surface to the cold one with a uniform velocity proportional to the temperature gradient. These results indicated a simpler explanation of the formation of the dark layer than that suggested by earlier writers.

In the present paper, we shall first of all describe an interferometric method of measuring temperatures and temperature gradients very close to a hot surface. In a recent note by Ramdas and Paranjpe[2] the importance of making such measurements accurately and the advantages of the interferometric method over the usual methods were briefly indicated. It was pointed out that the insertion of a thermo-couple, or a resistance thermometer, near a hot surface disturbs the isothermal layers of the air near it and vitiate the results. Apart from the inherent difficulties in setting up and handling a sensitive instrument like the interferometer, there are also certain types of deformation of the interference pattern which take place when one of the interfering beams passes through a region with a varying lapse-rate of temperature. It is therefore felt that a full account of the experimental method as well as the special experience gained in the course of the present investigation may be found useful by other workers. After setting out these details we shall discuss the interference patterns and the temperature gradients in the case of thin air cells between a hot surface above and a cold surface below similar to those used in the experiments on the

dark layer (*vide* Part I of this series). The discussion of other interesting cases like (1) the conditions above and below a single hot surface, and (2) above an evaporating surface, etc., will be taken up on a later occasion.

2. *Adjustment of the Interferometer.*

The arrangement of the optical plates and mirrors was essentially that of Mach-Zehnder.[3] A horizontal section of the apparatus is shown in Fig. 1. Light from a sodium vapour lamp S stopped down by a diaphragm D D and rendered parallel by a lens L_1 falls on a plane parallel glass plate P_1, is partially reflected on to the mirror M_2 and after one more reflection at M_2 is transmitted through a parallel plate P_2. We may call this beam A. The beam transmitted by P_1 which we may call B is reflected by the mirror M_1 and the

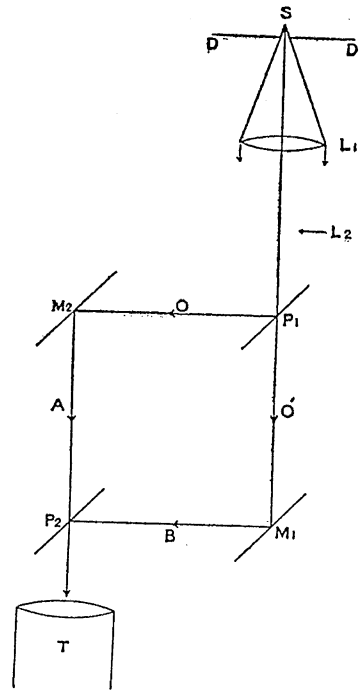


FIG. 1

plate P_2 and then interferes with the other beam. The two beams are seen through a telescope T while adjusting for the interference fringes.

The various movements which can be given to the different mirrors and plates and the details of their adjustments are as follows :—

(i) The plate P_1 can be turned about a vertical axis, but no fine adjustment has been provided.

(ii) The mirror M_1 is mounted on a platform which can move parallel to the line P_1M_1. It has an arrangement for rotation about a vertical axis and also for small rotation about a horizontal axis.

(iii) The plate P_2 can be rotated about a vertical axis.

(iv) The mirror M_2 has an arrangement for small rotation about a vertical axis.

(v) The plate P_1 and the mirror M_2 are both mounted on a rigid wooden beam which can be rotated about a horizontal axis parallel to the plane of P_1 or M_2. The axis of the wooden beam passes through its middle.

The above movements are sufficient to make the adjustments described below.

(*a*) The beam B can be rotated in a vertical plane because the mirror M_1 can move about a horizontal axis.

(*b*) The beam A can be rotated in a horizontal plane by turning the mirror M_2 about a vertical axis.

(*c*) The shifting of the beam B parallel to itself in a horizontal plane requires some explanation. Consider Fig. 2 (*a*). The mirror M_1 can be moved in the direction $\alpha\beta$. Suppose that $\alpha\beta\gamma\delta$ is the path of the ray when the mirror M_1 is in the position β. Let M_1 move to the position β'. The

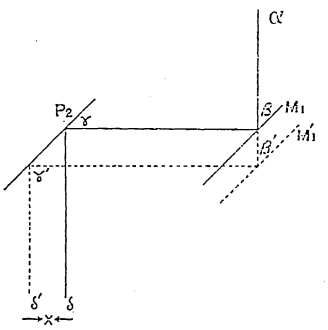


FIG. 2 (a)

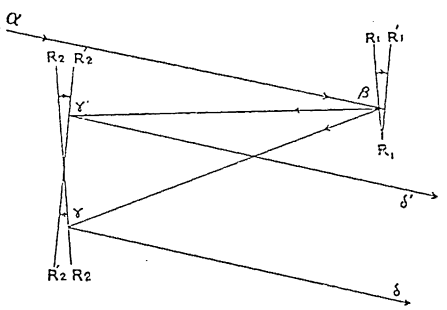


FIG. 2 (b)

path of the ray will now be $\alpha\beta'\gamma'\delta'$ with a lateral shift equal to x as indicated in the figure.

(*d*) We may now explain how the ray A can be shifted parallel to itself in the vertical plane. It may be recalled that the plate P_1 and the mirror M_2 (*vide* Fig. 1) are mounted on the same wooden beam which can be rotated about a horizontal axis parallel to the plane of M_2 or P_1. Such a rotation of the wooden beam involves a rotation of both P_1 and M_2 by exactly the same angle. The turning of P_1 deflects the ray A one way in the vertical plane but the turning of M_2 deflects the same ray in the opposite direction to

the same extent thus neutralising the rotation produced by P_1. Though these rotations neutralise each other the ray A gets a lateral shift parallel to itself in the vertical plane as shown in Fig. 2 (*b*).

Let R_1 and R_2 represent two surfaces reflecting a ray along the path $\alpha\beta\gamma\delta$. If now R_1 and R_2 rotate through the same angle and take up the positions R_1' and R_2', R_1' will now reflect the beam $\alpha\beta$ along $\beta\gamma'$ and R_2' will reflect it along $\gamma'\delta'$. The rotations are neutralised but $\gamma\delta$ is shifted parallel to itself to the position $\gamma'\delta'$.

Having described how to produce the rotations and lateral shifts of the beam A and B we proceed to show how fringes of any given (i) orientation in a vertical plane, (ii) width, and (iii) localisation may be obtained.

The light from the sodium lamp (see Fig. 1) is stopped down by a pin-hole in a black screen and rendered parallel by the lens L_1. We are therefore able to see in the telescope T two images of a bright source of light situated at infinity. We now turn the mirror M_2 about a vertical axis till the two images stand one above the other. A second lens L_2 is then thrown into position at the point shown by the arrow in Fig. 1 and forms images* at O and O′ of the point source at infinity. The telescope is now focussed for the images at O and O′. The images are brought one below the other by turning the plate P_2 about a vertical axis and when they are in the same vertical straight line, they are made to coincide by turning the beam carrying P_1 and M_2 about its horizontal axis.

The lens L_2 is now removed, the telescope focussed for infinity, and once more the two images are made to stand one above the other by turning M_2 about a vertical axis. After this the lens L_2 is again thrown into position and the above operations repeated.

The optical arrangement in Fig. 1 effectually enables us to produce two cones of light emerging from P_2 which have their apexes at infinity. When the apex of one beam is made to coincide with that of the other, the position may be roughly as shown in Fig. 3 (*a*). Now when the Lens L_2 is introduced the two beams come to a focus as in Fig. 3 (*b*) at N_1 and N_2. When N_1 and N_2 are made to coincide and the lens L_2 is then removed we have the two beams as in Fig. 3 (*c*). After repeating these adjustments a number of times we are able to bring A_1 and A_2 at a desired distance apart while keeping the angle of the two beams sufficiently small and obtain bright fringes localised at O or O′ (see Fig. 1).

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* O and O′ are points which can be anywhere in the paths $P_1M_2P_2$ and $P_1M_1P_2$ respectively.

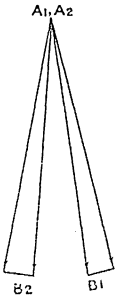


FIG. 3 (a)

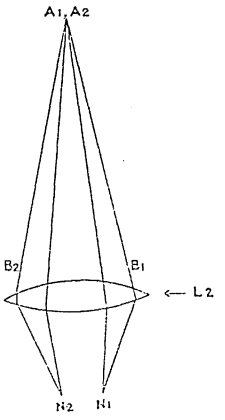


FIG. 3 (b)

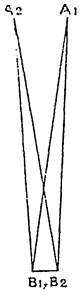


FIG 3 (c)

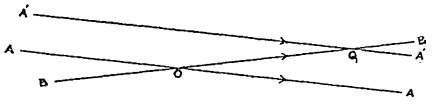


FIG. 3 (d)

It is worth noting that while making the above adjustments with the point-sources at infinity one beam is affected, while in doing the adjustments with the localised point-sources, it is the other beam that is affected.

(i) *Orientation of fringes* :—The direction of the interference bands is at right angles to the line joining the two virtual sources of light at infinity. Therefore to adjust the direction of the fringes we have simply to change the direction of the line joining the point-sources.

(ii) *Fringe width* :—Fringe width is inversely proportional to the distance between the sources of light.

(iii) *Localisation* :—We have shown above how the fringes are localised at O or O′. If now it is desired to change the localisation, it is necessary to turn the wooden beam carrying M_2 and P_1 about its horizontal axis. This adjustment shifts the beam A vertically up or down and shifts the plane at which the two interfering beams meet, without changing the angle between them. This is made clear by Fig. 3 (*d*). Let the two beams A and B meet at O. If the beam A is shifted parallel to itself to the position A′, the point

of intersection and therefore the position of the fringes moves over to the point Q.

Lastly we may add that an improvement in the clarity of the fringes is made possible by a slight movement of M_1 parallel to the line joining P_1 and M_1.

One special advantage of this type of interferometer† is that by following the above scheme of adjustments carefully the fringes can be localised at any desired point in $P_1M_2P_2$ or $P_1M_1P_2$ (Fig. 1) without change in the width or inclination of the bands. Usually, the experimental surface or medium is inserted between M_2 and P_2 or P_1 and M_1. It is necessary to localise the fringes at the point where these objects are inserted so as to obtain the actual distortion in the fringes in their neighbourhood. When this is done the whole pattern of fringes and the object inserted can be focussed simultaneously on a screen and photographed.

Now, if we insert a horizontal hot plate into the field of the interferometer the distortion of the fringe system is seen to depend upon whether we insert it between P_1 and M_1 or M_2 and P_2 (Fig. 1).

Case (i)—

The interfering wave fronts are shown as O A (corresponding to beam A) and O B (corresponding to beam B) in Fig. 4 (*b*) where the inclination between O A and O B is shown exaggerated. Let C D indicate the position and width of the horizontal hot surface which causes the wave-front to be distorted into A E O (when inserted between M_2 and P_2 of Fig. 1) as indicated by the dotted lines above and below the surface. The whole diagram is a vertical section of the arrangement in the plane parallel to the axis of the beams and represents a side view of the wave-front. The distortion of the wave-front A O is greatest near C D, and becomes negligible some distance away from the surface. The system of fringes moves away from the surface and at the same time becomes narrow above the plate, the minimum width occurring nearest to the hot surface. Below the surface the disturbed wave front is O E and it will be seen that the fringe system will move towards the surface and widen out at the same time, the widening being maximum nearest to the surface. Fig. 4 (*a*) shows the behaviour of the interference bands above the hot surface which is inserted only half-way into the field. The position of the hot surface is indicated by an arrow.

† Localisation of fringes at any desired point in the optical system without changing the fringe width is not possible with Michelson's arrangement of the interferometer.

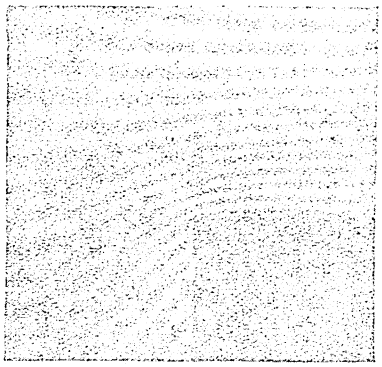


FIG. 4 (a)

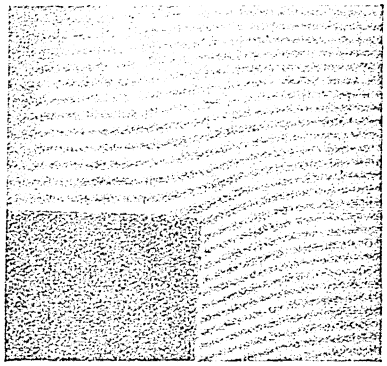


FIG. 4 (c)

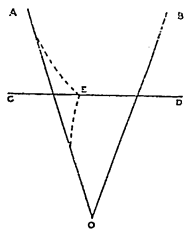


FIG. 4 (b)

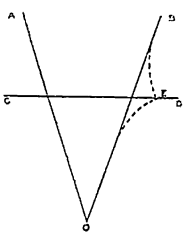


FIG. 4 (d)

Case (ii)—

Here the wave-front affected by the hot surface inserted between P_1 and M_1 (see Fig. 1) is O B which gets distorted into O E B as in Fig. 4 (*d*). In this case the movements of the fringe system would be exactly opposite to those observed in the previous case. The fringes above the surface widen out and move towards the surface and those below it contract and move away from it. Fig. 4 (*c*) shows the behaviour of the fringes above the surface and it will be noticed that the displacement and changes in width are exactly opposite to those in Fig. 4 (*a*).

Case (i) is to be preferred for the investigations of conditions above the surface as it provides a closer system of fringes for calculating air temperatures, and case (ii) is to be preferred for studying the conditions below the hot surface. In actual working the adjustment for either (i) or (ii) can be made without changing the position of the hot plate, by merely interchanging the positions of the wave-fronts O A and O B.

3. *Method of Calculation.*

When a hot surface is introduced half way into the field of the interferometer adjusted to give horizontal fringes, the fringes get shifted. These shifts can be used for calculating the temperatures of the air layers in the neighbourhood of the hot surface. The method of calculation given below closely follows that of Kennard.‡ Consider Fig. 5 (*a*). Suppose it represents the appearance of the fringes and the hot surface when the line of sight is parallel to the axis of the interfering beams. S_1S_2 is the hot surface and F_1F_1', F_2F_2' and F_3F_3', etc., represent the fringes. Let us fix our attention on the fringe F_3F_3'. It will be noticed that the left hand and right hand extremes of the fringe are horizontal. The fringe has shifted up by an amount F_3F_3'' equal to x cm. Also let F_2F_3 be equal to y cm. Then the shift expressed in fringe-widths is equal to x/y and we know that this must be equal to the change in the optical path of the light beam perpendicular to the plane of the figure by x/y wave-lengths. We shall denote the shift x/y by Δ N (in terms of the undisturbed fringe-width).

Having shown how the shifts are measured, we proceed to derive a formula connecting Δ N with the temperature of air at the point F_3'.

If n is the refractive index and ρ the density of air we have the Lorenz-Lorentz equation :

$$\frac{n^2 - 1}{n^2 + 2} = C\rho \qquad (1)$$

where C is a constant.

For air at ordinary pressures the above equation reduces to :

$$(n - 1) = \tfrac{3}{2} C\rho \qquad (2)$$

If N_1 is the number of light waves in a distance equal to the width of the plate S_1S_2 normal to the plane of the paper and n_1 the refractive index of the air near it when the surface is at air temperature, and if N_2 and n_2 are the corresponding quantities when the surface S_1S_2 is hot, then

$$n_1 = \frac{N_1}{N_0}$$
$$n_2 = \frac{N_2}{N_0} \qquad (3)$$

where N_0 is the number of waves over the same path in vacuum.

Further $N_0 = \frac{L}{\lambda_0}$, where L is the width of the plate and λ_0 the wave length *in vacuo*. From equation (2) we have :

$$n_1 - 1 = \tfrac{3}{2} C\rho_1$$

‡ *Bureau of Standards Journal of Research*, January-June 1932, 8, 791–792.

and

$$n_2 - 1 = \tfrac{3}{2} C\rho_2 \tag{4}$$

corresponding to the room temperature T_1 and the higher temperature T_2 at some point near the hot surface (T_1 and T_2 are in degrees absolute).

From (4) by subtraction :

$$n_1 - n_2 = \tfrac{3}{2} (\rho_1 - \rho_2) C \tag{5}$$

$$N_1 - N_1 = \tfrac{3}{2} C\rho_1 \frac{L}{\lambda_0}\left(1 - \frac{\rho_2}{\rho_1}\right) = (n_1 - 1)\frac{L}{\lambda_0}\left(1 - \frac{\rho_2}{\rho_1}\right) \tag{6}$$

Assuming that the pressure remains sensibly constant we have :

$$\frac{\rho_2}{\rho_1} = \frac{T_1}{T_2} \tag{7}$$

so that

$$\Delta N = (n_1 - 1)\frac{L}{\lambda_0} \cdot \frac{T_2 - T_1}{T_2} \tag{8}$$

where ΔN is put for $N_1 - N_2$. Equation (8) may be expressed as :

$$T_2 - T_1 = T_1 \frac{\Delta N}{\frac{n_1 - 1}{\lambda_0} L - \Delta N}$$

This relation can now be used for calculating T_2 at various distances away from the hot surface when T_1 the absolute temperature of room, L the width of the surface, n_1 the refractive index§ under room conditions and ΔN the shift in fringe-widths are known.

4. Method of End-Correction.

An interference fringe which is horizontal in the undisturbed portion of the field becomes horizontal above the hot plate only after passing through a certain region near the edge where it is inclined. From the variation of the slope of the fringe with distance it is possible to compute the end correction at the edge of the plate which is in the direction of the axis of the interferometer and apply this correction to the two edges of the plate which the beam of the light has to pass before it interferes with the other beam.

This method of applying the end correction is independent of the usual assumption with regard to equality of air temperature and the plate temperature at the hot surface.

Suppose we are looking at a horizontal hot surface from above. Let then S_1, S_2, S_3, S_4 represent the hot surface [see Fig. 5 (*b*)]. Now it is not only the air above the path S_4S_1 which will be hot but also the air at U and U′ near the edges of the plate. It is this that necessitates an end correction.

§ T_1 is actually measured and n_1 is calculated from the value of n_0 at N. T. P. for the actual value of humidity, pressure and temperature in the room during each experiment.

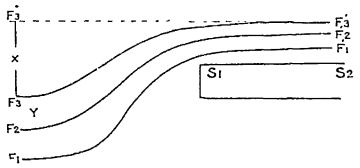


FIG. 5 (a)

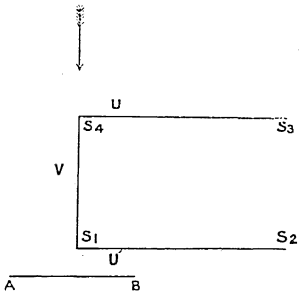


FIG. 5 (b)

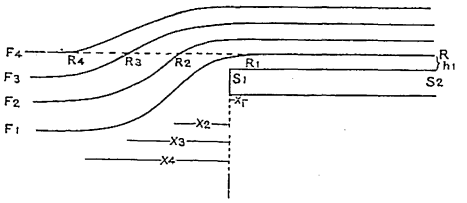


FIG. 5 (c)

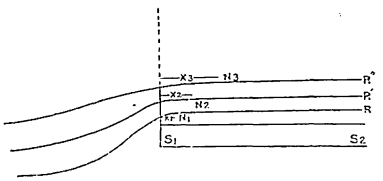


FIG. 5 (d)

Let the arrow represent the direction of the interfering beam of light and let AB represent the width of the field of view of the interferometer. Use is now made of the fact that the air at V is affected similarly to that at U and U'. Since the hot surface is only partly inserted in the field of view the fringe shifts in the left-hand part of the field of view must be attributed to the end effects alone.

Now consider Fig. 5 (*c*) which represents a vertical section of the hot plate half inserted into the interference field. S_1S_2 represents the hot plate. The bent lines are the interference bands.

Let it now be required to find the end correction at R which is h_1 cm. above the hot surface. Consider the points R_1, R_2, R_3, etc. on a line (dotted in the figure) drawn through R parallel to the hot surface. At R_2 the fringe shift is two fringe-widths. This shift must be attributed to a horizontal column of hot air at the level of R having its axis at a distance of x_2 cms. from the edge S_1 of the hot surface, and along the line of sight. The length of this column was assumed to a first approximation to be equal to L_0 the width of the hot surface. Therefore at a distance x_2 cm. the shift is $2/L_0$ fringe-widths per cm.

A number of values of the distance beyond the hot plate and the fringe shifts per cm. at these points are actually measured. From these a curve showing

the relation between the fringe shift per cm. and the distance x away from the edge is plotted. Let us now suppose that at a distance x from the edge of the plate the fringe shift per cm. is $F(x)$. The total fringe shift is then given by $\int F(x)dx$ the limits of integration being $x = 0$ and $x = X$ where X is the distance of a point towards the undisturbed portion of the field where the fringe shift vanishes.

The value of the integral as obtained from the graph referred to above therefore gives the magnitude of the shifts due to the end effects at the edges U and U′ Fig. 5 (*b*), and must therefore be subtracted from the observed shift at R. It is thus possible to find from separate graphs of $F(x)$ against x the end correction for different distances h_2, h_3, etc. above the hot surface. From Fig. 5 (*d*) it may be seen that the point where the interference band stops bending and becomes straight creeps in towards the plate as we proceed away from the surface (*vide* points N_1, N_2, N_3, etc.). This means that the end error begins to the left of N_1, N_2, N_3, etc. and that therefore it is only to the right of these points that the refractive index is constant. For the fringe R′ for example, we must take only $(L_0 - 2X_2)$ as the constant refractive index path (where x_2 represents the distance of N_2 from the edge).

5. *Temperature Distribution between a Horizontal Hot Surface Above and a Horizontal Cold Surface Below.*

We have already seen in our smoke experiments (see Part I) that when the separation between the two surfaces is of the order of 2 mm. or less the space between the surface is *totally* devoid of convection and that any smoke let into the air cell is rapidly repelled and deposited on the cold surface. There is no doubt that separations of the order of 2 mm. are to be preferred for the measurement of the heat conductivity in gases. In the experiments of Hercus and Laby[3] the separation used was as much as 6·28 mm. (temperature difference between the hot and cold surfaces was about 20° C.) and it was not therefore justifiable to assume that convection currents would have been absent at a pressure of one atmosphere. A reference to Figs. 2 and 3 of Plate XI in the earlier paper‖ will show that when the separation is 6·28 mm. the nature of the convection in the air cell would be intermediate between those seen in Figs. 2 and 3. Another point to note is that so long as traces of convection are present in the air gap it may not be justifiable to assume a constant temperature gradient from the hot surface to the cold one.

In the present section we shall discuss the interferometric measurements of temperature when the thickness of the air cell was 1·61 mm. and 0·77 mm.

‖ Paranjpe, *Proc. Ind. Acad. Sci.*, 1936, 4, 423.

respectively. In Plate XV, Figs. (*a*) and (*b*), the appearances of the interference fringes are shown enlarged for these two cases. The left half of each picture shows the air gap between the hot surface above and the cold surface below both of which are 5·2 cm. in width; the right half shows the undisturbed portion of the interference field. The temperatures of the two surfaces were maintained at about 83° C. and 33° C. respectively or with a temperature difference of the order of 50° C. The upper surface was heated electrically and the cold surface was maintained at a constant temperature by circulating water. The temperatures of the two surfaces were measured by means of thermal junctions in the usual way.

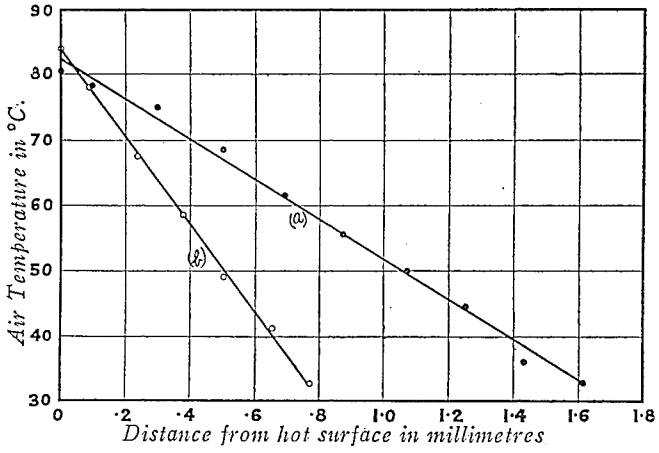


FIG. 6.

The variation of temperature with distance between the two surfaces was calculated by employing the methods described in the two preceding sections. The temperature-distance relations are as shown by the curves (*a*) and (*b*) in Fig. 6.

It is interesting to note that the distribution of temperature is sensibly linear in both the cases.

6. *Summary.*

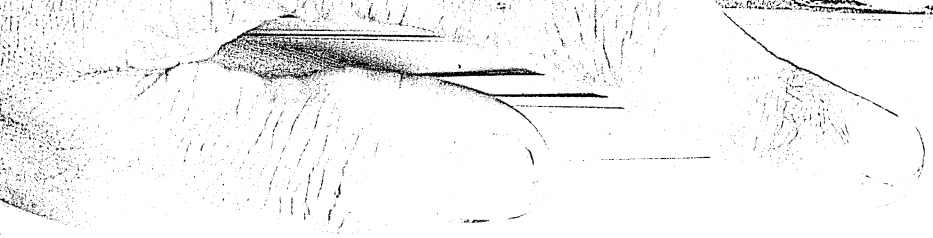
The paper describes an interferometric method of measuring the temperature distribution near hot surfaces. The details of the method and the various precautions to be taken are discussed. The distribution of temperature in the case of a horizontal air cell between a hot surface above and a cold surface below is discussed in relation to convection and the importance of using small air gaps (2 mm. or less) in thermal conductivity measurements is pointed out. Pictures of the interference pattern when the air cell is 1·61 mm.

and 0·77 mm. thick are given along with the temperature distributions calculated from these pictures.

In conclusion, the author's best thanks are due to Dr. L. A. Ramdas for the suggestion of the problem and guidance in the course of the investigation. He is also grateful to the Director-General of Observatories for the facilities given at the laboratories of the Meteorological Office at Poona and to Professor S. D. Bhave, S. P. College, Poona, for the loan of the interferometer.

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2. Ramdas, L. A., and Paranjpe, M. K., *Current Science*, March 1936, 642.
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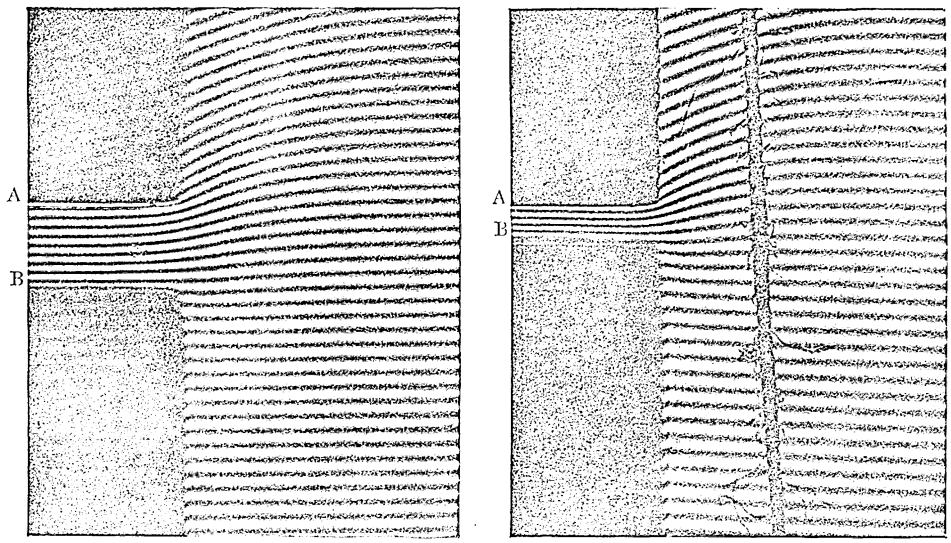
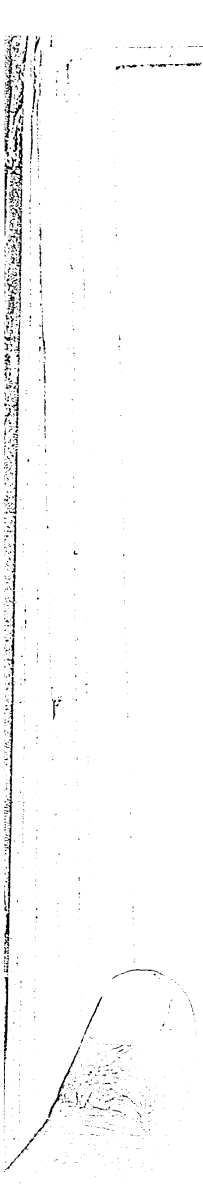
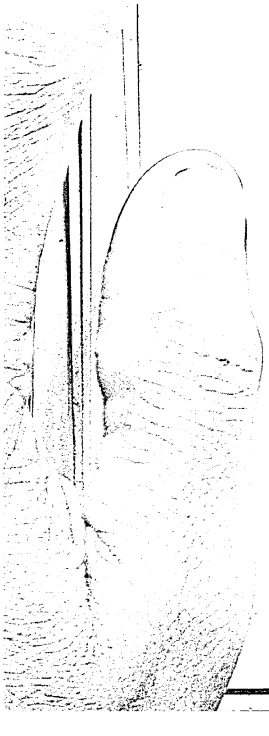


FIG. (*a*) FIG. (*b*)

A is the upper hot surface and B the cold surface below it. AB = 1·61 mm. in fig. (*a*) and 0·77 mm. in fig. (*b*). (The rugged object stretching across the field of view in fig. (*b*) is a piece of thread suspended in the plane in which the fringes are localized; it was accidentally not removed before the picture was exposed, but shows the accuracy with which localization can be achieved.)





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THE CONVECTION AND VARIATION OF TEMPERATURE NEAR A HOT SURFACE.

Part I. The Dust-Free or Dark Layer in Relation to Surface Convection.

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(Communicated by Dr. L. A. Ramdas, M.A., Ph.D.)

1. *Introduction.*

Tyndall[1] reported in 1870 that in the convection currents rising from a hot body a dark or dust-free region becomes visible when the space near the hot body is illuminated suitably by a strong beam of light. Later, this phenomenon was investigated by a number of other workers.[2,3,4,5]. The investigations of Aitken and Lodge and Clark about 1884 brought out the important fact that after accounting for the secondary dust-clearing effects which are produced by (1) the action of heat on clouds of volatile substances, (2) the vertical settling of dust as differentiated from horizontal movements due to convection in the neighbourhood of hot or cold bodies, and (3) the possible centrifugal action associated with the convection round the edges of hot bodies, there still remains the major effect due to the repulsion experienced by dust particles in the neighbourhood of a hot surface (or the attraction experienced by them when they approach a surface which is colder than the air). Aitken and Lodge and Clark showed that, owing to this repelling effect, there is a film of dark or dust-free air surrounding a hot body when it is kept in a dusty atmosphere, and that this film is the source from which the dark ascending cone of hot air above the body draws its supply. The above workers used hot objects of small dimensions in their experiments. Ramdas and Malurkar[6] showed from their experiments with hot plates of large dimensions that the convective heat transfer to the air above the plate is associated with the rising cones of dust-free air which escape from the primary skin layer not at one place but at a number of places and move about in a random manner. Below the extensive hot plate Ramdas and Malurkar found that the dark layer remains more or less uniform.

The convection and distribution of temperature below a hot surface are of great importance in all investigations where the heat transfer across

a gas is under consideration. The present writer undertook a further investigation of this problem at the suggestion of Dr. L. A. Ramdas. The convection below the hot plate and the dark or dust-free layer were studied by the optical method using a dusty atmosphere and a beam of light; the distribution of temperature below the surface was investigated by an interferometric method.

In the present paper we shall confine our attention to certain experiments on the dark layer below a hot surface, for this case is simple to consider. These experiments have led to some new results in the light of which the explanations offered by Aitken and Lodge and Clark would require revision. We shall deal generally with particles in the smoky air which are neither volatile nor hygroscopic.

2. *Summary of Previous Work on the Thickness of the Dark or Dust-Free Layer.*

Before entering into a discussion of our results it will be necessary briefly to summarise the main results of previous workers on the dark layer. We reproduce here (Fig. 1) the usual diagram showing the nature of the

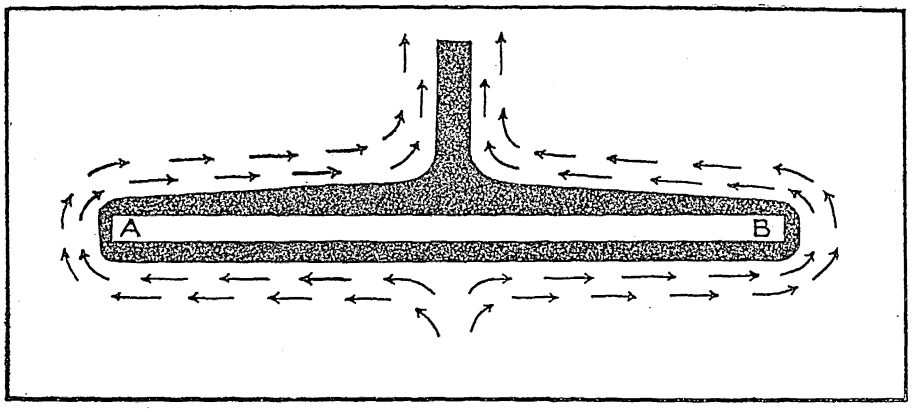


FIG. 1.

convection and the distribution of the dark space when a hot metal plate, say 2 or 3 cm. square, is kept horizontally in an observation chamber containing dusty air. A B is a vertical section of the hot plate and the dark layer which appears under illumination is uniform in thickness below the plate whereas above the plate there is a dark pillar of rising hot air at the centre. Both above and below the plate the outer boundary of the dark layer is sharp. The arrows in the figure indicate the nature of the convectional movements under these circumstances. The air layers below undergo a slight sidewise flow, turn round the edges and then, drifting slightly

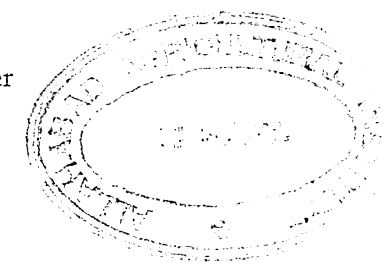
towards the centre of the plate, rise upwards. As long as the plate A B is warmer than the air surrounding it, the movements shown in Fig. 1 persist.

(*a*) *Effect of temperature.*—The effect of increasing the temperature of the hot plate has been shown by Lodge and Clark to be to increase the activity of the convective movements in the air. The increase of temperature facilitates the formation of the dark layer more than the increased velocity of the convection currents reduces its thickness. The increase in the thickness of the dark layer with increase of temperature is not, therefore, very conspicuous.

(*b*) *The effect of pressure.*—Lodge and Clark have measured the thickness of the dark layer at different pressures of the surrounding air. The table below is reproduced from their paper.

TABLE I.

Pressure of air in centimetres of Hg.	Thickness of layer in centimetres
75·9	·013
20·8	·027
10·9	·054
3·9	·083



The reduction of the pressure in the ratio of 1 : 20 has caused a reduction of the thickness in the ratio of 1 : 6.

(*c*) *Effect in different gases.*—Lodge and Clark estimated the thickness of the dark layer when the hot surface was kept in different gases. Their results are given below :—

	Thickness of coat in cm.
Hydrogen	·033
Ammonia	·013
Air	·020
Carbonic acid gas	·011

While the temperature conditions do not appear to have been kept strictly comparable in the experiments with the different gases it is easy to infer that in a light gas like hydrogen the thickness is roughly three times that in the case of carbonic acid gas.

(*d*) *Effect of convection.*—By forcing a current of air against a hot surface one can thin out the dark space and make it ultimately disappear. In otherwise still air, however, the effect of the natural convection which is set up as soon as the hot plate is introduced is to make the dark space slightly thinner below than above ; above the centre of the hot plate the air which

is being made dust-free all round the plate accumulates and rises up vertically as seen in Fig. 1.

A consideration of the above results leads one to the conclusion that we have to reckon with two factors which work in opposition so far as the conditions below the hot plate are concerned. One of them is the repelling force experienced by a dust particle when it goes very close to a hot surface. The repulsion of the particles approaching the surface is opposed by the forces set into operation by the convection pattern below the dark layer.

We shall now describe some experiments made at Poona by the present writer in order to elucidate the problem further.

3. The Dark Layer between Two Horizontal Plates.

The convective movements above and below a hot plate make the interpretation of results somewhat difficult. From Fig. 1 one can see that the movements above the plate cause a continuous leakage of the dust-free air formed all round the plate and variations due to temperature and nature of the gaseous medium do not offer results which are sufficiently striking or conclusive. We have accordingly modified the experiments as below :

A vertical section of the apparatus used is shown in Fig. 2. A B C D is a rectangular vessel made of tin. The cross-section is about 5 cm. by 5 cm.

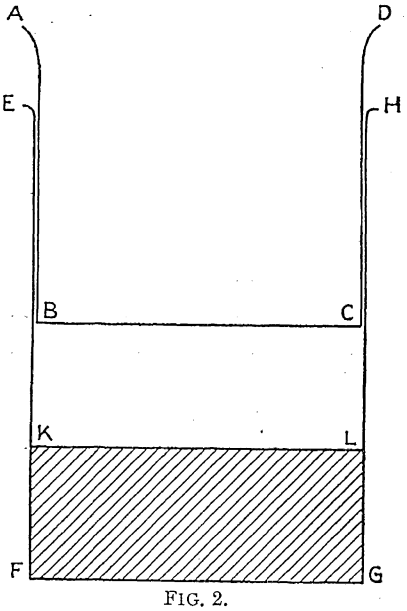


FIG. 2.

This vessel fits exactly into a glass cell E F G H. The lower surface of B C is ground flat. Mercury is poured into the glass cell up to any desired level K L. The metal surface B C is heated by pouring hot water into the vessel

A B C D. To study the phenomena in the interspace, cigarette smoke is introduced into the space between B C and K L and a parallel beam of light allowed to enter at B K and to get out at C L. The beam is passed through a narrow slit placed vertically outside at the centre of the face B K so that one sees a vertical cross-section of the phenomena taking place between B C and K L. The distance between B C and K L was 2·29 cm., 0·85 cm., 0·54 cm., 0·34 cm. and 0·22 cm. respectively in the different experiments. The results in the different cases are described below. In the experiments referred to below the upper hot surface was always maintained at 75° C. and the cold surface at room temperature.

Case 1: *Separation between the surfaces* = 2·29 *cm.*—The vertical section of the convection pattern is shown in Plate XI, Fig. 1. There is a thin dark layer just below the hot plate. The space below this dark layer is occupied by a pair of vortices. The direction and movement of the two vortices is as shown in Fig. 3. The vortex on the right hand moves clockwise and the one on the left anti-clockwise. At the centre of the pattern the air is seen rising towards the hot surface. The figure immediately suggests that the convection in the two vortices would tend to throw out a particle towards the hot surface on account of the centrifugal action whereas the repelling effect of the hot surface would act in the opposite way; the vortices appear to compress the dark space. The thickness of the dark space is only about 0·5 mm.

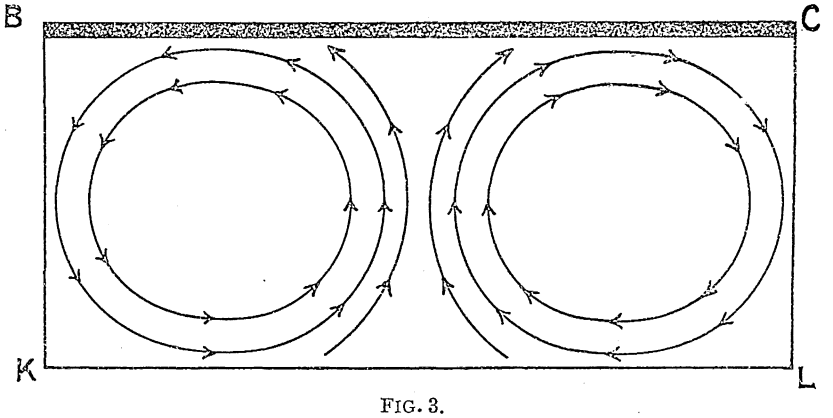


FIG. 3.

Case 2: *Separation between the surfaces* = 0·85 *cm.*—On decreasing the distance between B C and K L, the two vortices decrease in size, separate and move towards the two sides of the cell, as shown in Plate XI, Fig. 2. The air in the middle portion of the cell is free from any convectional movements, and here the repelling effect of the hot surface on the smoke particles

has its full sway. At the two ends of the cell the vortices, though smaller and less vigorous, still exercise a controlling effect, but even here the dark space is wider than in the previous case. The maximum width at the centre is of the order of 4 mm. Thus, a reduction in the distance between B C and K L from 2·29 cm. to 0·85 cm., *i.e.*, to a third of the original value has caused an increase in the width of the dark space from 0·5 mm. to 4 mm., *i.e.*, an eight-fold increase.

Case 3: *Separation between the surfaces* = 0·54 *cm.*—A further reduction of the distance between B C and K L brings about a rapid contraction of the vortices which now become very sluggish. The appearance of the pattern is shown in Plate XI, Fig. 3. The dark region now occupies the whole space between the two plates, the smoke being driven towards the cold surface everywhere except at the two ends where also, above the vortices, the dark space has widened still further.

The dark space at the centre which is equal to the distance between the two surfaces is now 5·4 mm.

Case 4: *Separation between the surfaces* = 0·34 *cm.*—Plate XI, Fig. 4 shows the pattern when the space is reduced to 0·34 cm. Smoke particles are absent everywhere except at the two ends where the last remnants of the two original vortices are just visible.

Case 5: *Separation between the surfaces* = 0·22 *cm.*—Lastly Plate XI, Fig. 5 shows the conditions when the distance between B C and K L is of the order 2·2 mm. At this distance smoke particles are driven away towards the cold surface as soon as they are introduced.

We thus see from Figs. 3, 4 and 5 of Plate XI that as soon as the hot surface comes to within 5 mm. of the cold surface the vortices and the movements associated with them tend to disappear. The controlling influence of convection being absent, the force of repulsion experienced by a particle near the hot surface continues to act on the particle until it is pushed away completely towards the cold surface.

There is a variation of the above series of experiments which leads to some further interesting results. The air in the space between B C and K L (Fig. 2) is kept free from smoke to start with. Hot water is poured into the upper vessel so as to heat the surface B C. After the air in the interspace has had time to take up the temperature gradient a puff of smoke is introduced gently through a narrow metal tube soldered to a small hole at the centre of B C. The puff of smoke does not show any trace of convection or tendency to spread sidewise if the distance between B C and K L is less than about 5 mm. The puff of smoke is seen to undergo a rapid vertical movement

downwards towards the cold plate B C, the upper boundary of the smoke layer being quite sharp. In the course of a few seconds all the smoke is repelled towards the cold surface and deposited on it.

The speed of the downward movement becomes more and more rapid as the distance between B C and K L is decreased. On the other hand, if the distance between them is increased to a centimetre or so, the downward movement becomes slower, the smoke partakes of the convectional movements which are associated with this distance between the two surfaces, and the upper boundary of the smoke layer remains at a distance of about 2 or 3 mm. away from the hot surface.

We thus see that the repulsion experienced by the smoke particles increases as the distance between the two surfaces is decreased. The fact that convective movements in the interspace are absolutely unnecessary to bring about a repulsion of the particles directly upsets the explanation offered by Lodge and Clarke, who supposed that a motion of the smoky air parallel to the hot surface is essential for the production of the dark layer (*loc. cit.*, pp. 234–39).

The above experiments with the two surfaces close to each other immediately suggest that we may investigate the phenomenon of the dark layer in a quantitative manner by measuring the rate at which the smoke layer* moves downwards away from the hot surface B C. The results of such a quantitative study when (1) the hot and the cold surfaces are maintained at definite temperatures, but the distance between them is varied and (2) the two surfaces are kept at a constant distance apart, but the temperature of the hot surface is varied, are described below.

The smoke was let into the cell (space between B C and K L) and the rate of movement of the smoke layer measured with the help of a stop-watch while another observer watched the movement of the smoke through a convex lens and an eye-piece provided with a graticule. The magnification of the optical system being known, the actual distances travelled by the smoke can be estimated readily.

(1) *Effect of changing the distance between the surfaces on the repulsion of the smoke layer.*—In this series of experiments the temperature of the upper surface B C was maintained at 70° C., *i.e.*, about 40° C. above that of the cold surface. The distance traversed by the smoke layer at various instants after its introduction into the cell was recorded when the separation between B C and K L was 9·0 mm., 6·0 mm. and 3·5 mm. respectively. These observations

* By the "smoke layer" we shall hereafter mean the sharp upper surface of the smoke layer.

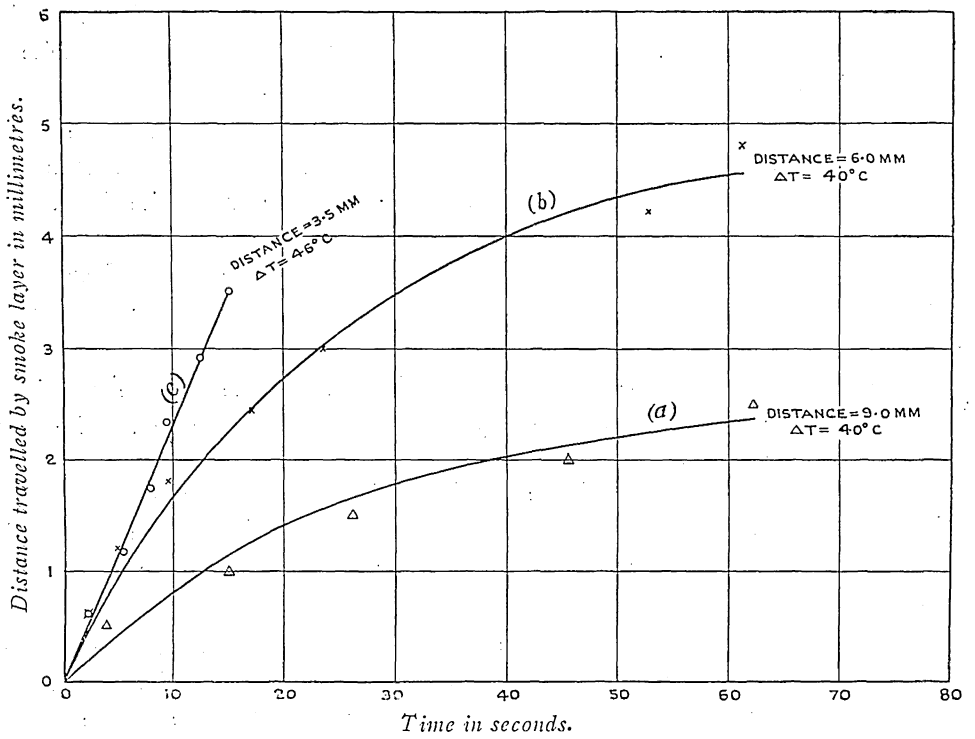


FIG. 4.

are plotted in curves (*a*), (*b*) and (*c*) in Fig. 4. From these curves we see that the rate of movement of the smoke layer was most rapid as well as uniform when the hot and the cold surfaces were nearest to each other. For example the velocity indicated by curve (*c*) is larger than that indicated by either (*a*) or (*b*) in Fig. 4, and the distance—time relation is represented by a straight line ; when the distance between the hot and the cold surfaces is increased, the particles of smoke move at smaller velocities and also less and less rapidly as they recede from the hot surface. The velocities attained by the smoke layer at different distances away from the hot surface were calculated from the curves in Fig. 4 and are given in Table II below.

The falling away of the velocity as the particles move away from the hot surface when the thickness of the air cell is 0·6 cm. or more shows that the opposing influence of convection begins to be felt in these cases. When the thickness of the air cell is 0·35 cm. or less the particles move with a uniform velocity throughout their passage from the hot to the cold surface ; in this case convection of the air in the cell is absent as we have already seen.

(2) *Effect of changing the temperature difference between the hot and the cold surfaces while keeping the distance between them constant.*—From the

TABLE II.

Distance between hot surface B C and cold surface K L in cm.	Distance of smoke layer from the hot surface in cm.	Velocity of the smoke layer in cm./sec.
0·90	0·05	0·0083
	0·15	0·0034
	0·24	0·0000
0·60	0·05	0·0182
	0·15	0·0143
	0·25	0·0111
	0·35	0·0054
	0·46	0·0000
0·35	0·05	0·0226
	0·15	0·0226
	0·25	0·0226
	0·35	0·0226

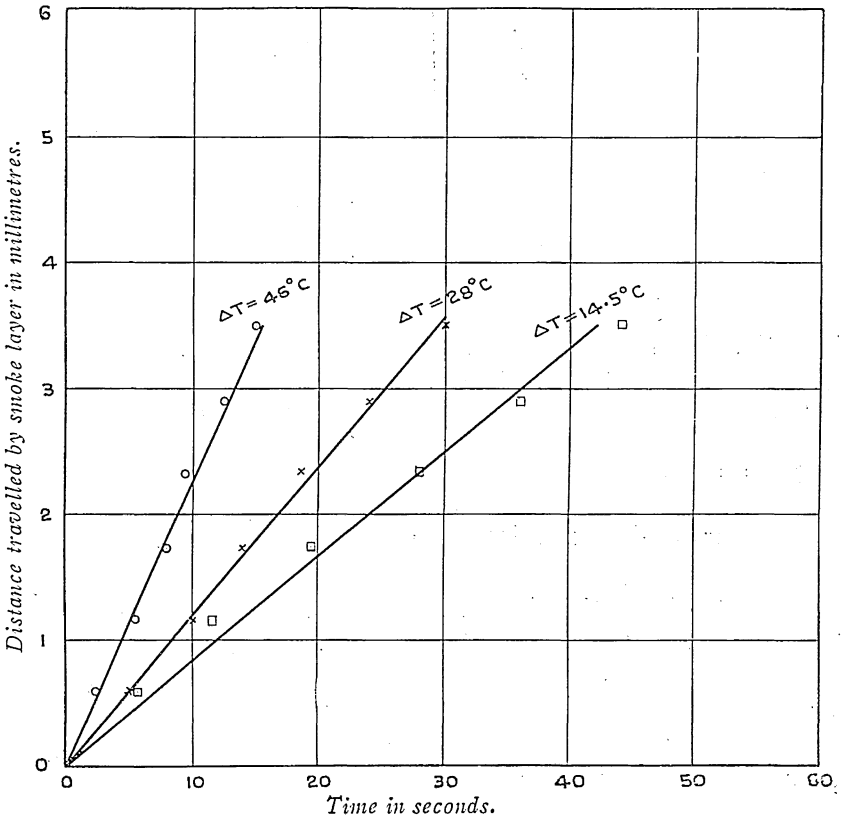


FIG. 5.

previous section it is clear that the experiments for detecting the variation of velocity with temperature gradient will be most instructive when the hot and cold surfaces are kept at 0·35 cm. or less from each other. In this case the smoke travels with a uniform velocity and the dark layer occupies the whole space between the two surfaces.

The temperature differences $\triangle T$ between the hot and the cold surfaces were adjusted to be 46° C., 28° C. and 14°·5 C. respectively and the rate of movement of the smoke layer measured as before. These measurements have been plotted in Fig. 5. The graph of distance traversed (d) against time is a straight line in each case. The mean velocities of movement of the smoke for different values of the temperature gradient as calculated from these graphs are given in Table III below.

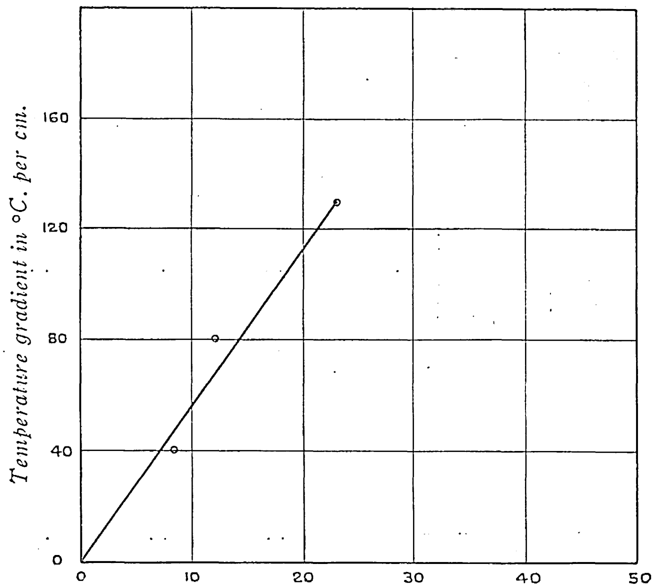
TABLE III.

Temperature gradient in °C. per cm. $\left(\frac{\triangle T}{d}\right)$	Mean velocity of the smoke layer in cm./sec.
131	·0226
80	·0119
41	·0083

From the above values a graph of velocity against temperature gradient has been drawn (see Fig. 6). It is interesting to note that the graph is nearly linear. The relation between velocity (v) and temperature gradient $\frac{\triangle T}{d}$ may be expressed as

$$v = 1 \cdot 756 \times 10^{-4} \times \frac{\triangle T}{d}.$$

Having established that in the above experiments (where convection in the air cell is eliminated by bringing the hot and cold surfaces sufficiently close to each other) the smoke particles move with a velocity proportional to the temperature gradient, we may now discuss how this result may be utilised for computing the force of repulsion experienced by a smoke particle in the neighbourhood of a hot surface.



Velocity of smoke layer in centimetres per second × 10^3

FIG. 6.

4. *Calculation of the repulsive force experienced by a smoke particle in the neighbourhood of a hot surface.*

From a knowledge of the velocity of a smoke particle we can estimate the force of repulsion experienced by it when it is near a hot surface.

For the free fall of a spherical particle of radius r under the influence of gravity the limiting velocity (according to Stokes' law[7]) is given by

$$6\,\pi\eta r v' = \tfrac{4}{3}\pi r^3 (\rho - \rho')\, g \text{ or}$$

$$v' = \tfrac{2}{9}\,\frac{r^2 (\rho - \rho')\, g}{\eta} \qquad (1)$$

where

v' is the limiting velocity of the particle,

ρ is the density of the particle,

ρ' is the density of air,

g is the acceleration due to gravity, and

η is the viscosity coefficient of air.

If, in addition to gravity there is an additional force F (to which the influence of the hot surface may be considered as being equivalent) in the same direction, the limiting velocity v'' is given by

$$6\,\pi\eta r v'' = \mathrm{F} + \tfrac{4}{3}\pi r^3 (\rho - \rho')\, g$$

so that

$$\frac{v''}{v'} = \frac{F + \frac{4}{3}\pi r^3 (\rho - \rho') g}{\frac{4}{3}\pi r^3 (\rho - \rho') g}.$$

If the size of the particle is small compared to the mean free path[8,9] λ, the limiting velocities v' and v'' will be altered to v_1 and v_2 which are given by

$$\left.\begin{aligned} v_1 &= v'\left(1 + K\frac{\lambda}{r}\right) \\ \text{and} \quad v_2 &= v''\left(1 + K\frac{\lambda}{r}\right) \end{aligned}\right\} \quad .. \quad .. \quad .. \quad .. \quad .. \quad (2)$$

where K is a constant equal to 0·86 and $\lambda = 6{\cdot}32 \times 10^{-6}$ for air at N. T. P. From (2) we have

$$\frac{v_2}{v_1} = \frac{v''}{v'} \text{ so that}$$

$$\frac{v_2 - v_1}{v_1} = \frac{F}{\frac{4}{3}\pi r^3 (\rho - \rho') g} \quad .. \quad .. \quad .. \quad .. \quad (3)$$

Let us consider the case where the hot and the cold surfaces are at 75° C. and 29° C. respectively and 3·5 mm. apart. The values of η at these temperatures are $2{\cdot}090 \times 10^{-4}$ and $1{\cdot}875 \times 10^{-4}$ c.g.s. units respectively so that for a mean temperature of 52° C. of the air between the two surfaces we have a mean value of η equal to $1{\cdot}98 \times 10^{-4}$. Neglecting ρ' and putting $r = 2{\cdot}5 \times 10^{-5}$ cm. (results of our measurements) and $\rho = 2{\cdot}3$ (density of carbon) we have from equations (1) and (2)

$$v_1 = 1{\cdot}93 \times 10^{-3} \text{ cm./sec.}$$

From our measurements we know that for this particular case v_2 was equal to $22{\cdot}6 \times 10^{-3}$ cm./sec. so that substituting in equation (3) we have

$$\frac{F}{\frac{4}{3}\pi r^3 \rho g} = \frac{(22{\cdot}6 - 1{\cdot}93) \times 10^{-3}}{1{\cdot}93 \times 10^{-3}} = 10{\cdot}71.$$

$$\therefore F = \tfrac{4}{3}\pi r^3 \rho g \times 10{\cdot}71$$

The excess of pressure ΔP exerted by the particle on account of this extra force due to a temperature gradient of 131° C. per cm., will be

$$\Delta P = \frac{F}{\pi r^2} = \tfrac{4}{3}\pi r^3 \rho \times \frac{10{\cdot}71 g}{\pi r^2}$$

$$= 0{\cdot}81 \text{ dyne/cm.}^2$$

This excess of pressure is due to the more vigorous impacts on the side of the particle facing the hot surface than on the side facing the cold surface. The pressure is too small to be detected by ordinary methods but is sufficiently large to affect the small particles we are considering.

Summary.

The paper discusses the formation of the dark or dust-free layer in the space between a hot surface (above) and a cold surface (below). The variations of the dark layer (1) with distance between the surfaces when the temperatures of the two surfaces are kept unaltered and (2) with the temperature gradient when the distance is kept constant at 3·5 mm. have been studied. It is shown that when the distance between the two surfaces is less than 4 mm. the whole space is occupied by the dark layer. If smoke is introduced into this space it travels from the hot to the cold surface with a velocity proportional to the temperature gradient. The excess of pressure associated with the velocity of the particle is calculated.

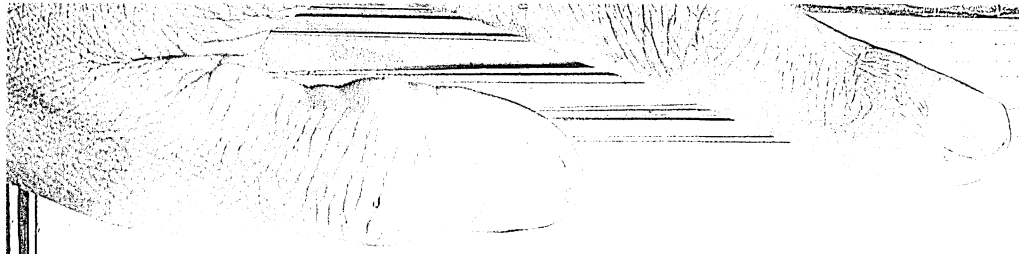
Conclusion.

These investigations are being continued at different pressures and with particles of different sizes. The applications of interferometry to the study of the phenomena near a hot surface will be discussed in the next part of this series.

In conclusion, the author has great pleasure in expressing his best thanks to the Director-General of Observatories for facilities given at the laboratories of the Meteorological Office at Poona and to Dr. L. A. Ramdas for his guidance.

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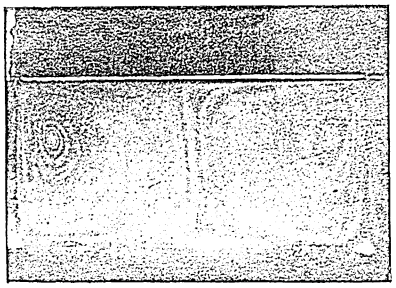


FIG. 1.

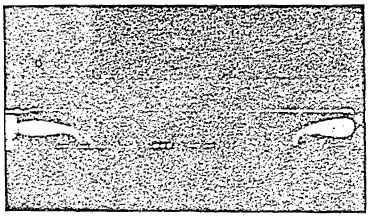


FIG. 3.

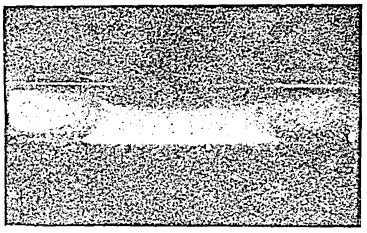


FIG. 2.

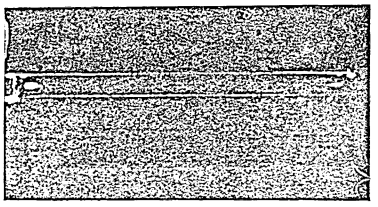


FIG. 4.

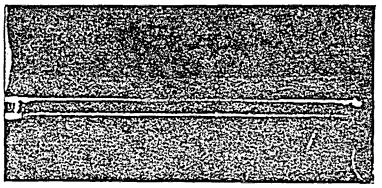


FIG. 5.

Development of the dark layer as convection in the air cell is decreased by bringing the hot and the cold surfaces together.

FACULTY

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THE MEASUREMENT OF THE TRANSMISSION OF HEAT BY CONVECTION FROM INSOLATED GROUND TO THE ATMOSPHERE.

By P. K. Raman.

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(Communicated by Dr. K. R. Ramanathan, D.Sc.)

Introduction.

For more than six hours on a clear day in tropical and subtropical continental areas, the ground is often more than 15° C. warmer than the air at a level of 4 ft. above ground, and at the time of maximum ground-temperature, the excess may be as much as 25–35° C. This implies the transfer of a considerable amount of heat every day from the heated ground to the atmosphere and this process of convective heating plays a large part in determining the thermal properties of the air over these regions. A few attempts have been made by European workers[1,2,3] to estimate the quantities of heat transferred to the atmosphere by convection in temperate regions. But quantitative measurements are few and the methods are often indirect. Dines[2] estimates the average daily addition of heat throughout the earth by convective processes to be 200 calories/cm.^{2} This includes the heat (150 cal./cm.^{2}) contributed by condensation of moisture. In the present paper is described a simple apparatus for determining the rate at which heat is transferred from dry ground to the atmosphere; the instrument was used to determine the quantity of heat transferred to the atmosphere by convection on a number of days in clear weather at Poona during the period, January-May 1935. The results of the open-air measurements are compared with those from laboratory experiments obtained by other workers and it is shown that a simple formula can be used for estimating the rate at which heat is transferred to the atmosphere from heated ground in terms of the surface temperature of the ground and the meteorologically measured quantities, temperature of air and wind-velocity at 4 ft.

As a problem of general ærodynamics, the subject of heat transfer from a hot body by convection to the surrounding fluid has been investigated by a number of workers, both experimentally and theoretically. When the fluid has no general movement, but has only internal movements arising from the differences of density caused by the contact of portions of the fluid

with the hot solid, the convection is called 'free' or 'natural'; when a general movement of the fluid is super-posed, the convection is called 'forced'. In the atmosphere natural convection is of comparatively less importance, as absolute calm is very rare, especially in the hot hours of the day. For theoretical calculations, the surface of the earth may be considered as a rough horizontal plane of infinite extent and the stream of fluid roughly parallel to the surface.

Apparatus and Method of Measurement.

The apparatus used for measuring the rate of transfer of heat is similar in principle to that of the Angstrom's Pyrgeometer. A thin polished silver-plated constantan strip AB (Fig. 1) is mounted between the ends of a pair

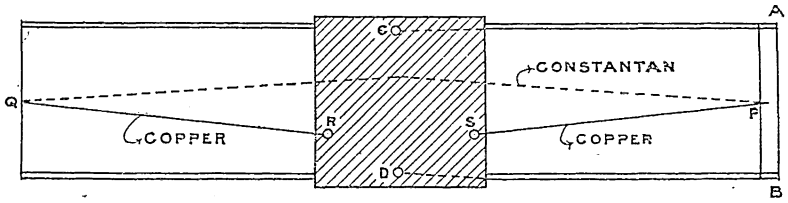


FIG. 1.

of parallel copper rods (nickel-plated and polished) carried on a base of ebonite. The copper rods are connected to two terminals C and D. One junction P of a copper-constantan thermo-couple is placed in thermal contact with the centre of the surface of the strip AB; the other junction at Q being suitably mounted on silk fibres so that it can be placed in contact with the surface under investigation. The under-side of the constantan strip is lined with a layer of cork so that when placed on the ground it is thermally insulated from it. R and S are the terminals for connecting the thermo-couple to a suspended coil galvanometer. The strip can be heated electrically as required and the current measured on a calibrated ammeter. The convection apparatus was exposed in the open while the battery, electrical instruments, etc., were housed in an adjoining hut.

The measurements were made on clear days during the winter of 1935 at the Agricultural Meteorological Observatory at Poona which is situated in an open place well removed from buildings. On a selected plot of level ground the apparatus was placed with the under-surface of the strip thermally insulated from the ground and the junction Q in thermal contact with the soil surface. The upper surface of the strip was placed flush with the surface of the ground (but not actually touching it) so as to reduce the boundary effects to a minimum. The current required to be passed through the strip when it was at the same temperature as the soil surface was measured,

Because of turbulent wind movements a perfectly steady null position could not be obtained. The reading of the current was taken when the galvanometer oscillated symmetrically about its zero position.

When the strip is in thermal equilibrium with the surface of the ground it gains heat energy from the electric current passing through it, and from the radiation of the sun and the sky; it loses heat by long wave radiation and by convection. The convective loss which is equal to that of the surrounding ground can be evaluated if the gain and loss of heat due to the remaining factors can be determined.

The energy consumed for heating the strip can be calculated from the current i, the resistance R and the area A of the strip. Thus

$$H = Ki^2 = \frac{60\,R}{AJ} i^2 \text{ gm. cal./cm.}^2 \text{ min.} \quad .. \quad .. \quad .. \quad (1)$$

To estimate the loss or gain of heat by radiation we require the effective absorptivity of the strip both for visible and for infra-red radiation. These were determined experimentally as below.

A Pyrheliometer of the Angstrom type was constructed with two strips of constantan cut from the same strip as was used for the convection instrument. One strip was kept with the original polish on and the other was given a thin uniform coating of lamp black. A series of measurements were taken with this Pyrheliometer with both the strips or the black strip alone successively exposed to direct solar radiation. From these the percentage of the incoming energy absorbed by the bright strip can be calculated. The average of a series of measurements showed that the bright strip absorbed 0·25 of the incident solar radiation. This same Pyrheliometer was used as a Pyrgeometer for measurements of nocturnal radiation and comparative observations taken with a standard Angstrom Pyrgeometer showed that the effective absorptivity of the bright strip was not appreciably different from 0·25 for thermal radiation also.

The heat transferred to the air from unit area of the strip in a unit of time by convection can be calculated as follows :—

$$H = \frac{Ri^2}{AJ} + a\Sigma + a_1 (s - \sigma T^4) \quad .. \quad .. \quad .. \quad (2)$$

where

H is the heat transferred by convection in gm.cal./cm.^{2} min.,

i is the heating current in amperes,

R and A are the resistance and area of the strip respectively,

Σ solar and visible sky radiation on a horizontal surface in gm.cal./cm.^{2} min.,

s atmospheric radiation (gm.cal./cm.^{2} min.) obtained from the mean of observations with Angstrom's Pyrgeometer on the previous night,

σT^4 the black body radiation (gm.cal./cm.^{2} min.) at the temperature T° Absolute of the ground at the time of observation ; σ being the Stefan-Boltzmann constant,

a and a_1 are the effective absorptivities of the strip for solar radiation and for long wave radiation respectively.

Measurements were also taken of the following elements before and after each reading with the convection apparatus :—

(1) The temperature of the surface of the ground with a surface thermometer.

(2) The temperature of the air above ground by an Assmann thermometer at about 1 cm. above surface.

(3) The temperature of the air at 4 ft. (from thermometer in Stevenson screen).

(4) The wind-velocity at the two levels 1½ ft. and 6 ft. by Robinson cup anemometers.

(5) The radiation from the sun and the sky received on a horizontal surface at the time of each observation as read off from the Kipp and Zonen, Solarigraph installed at the Observatory.

Results and Discussion.

Measurements of heat loss from ground due to convection show considerable fluctuations especially when the excess temperature of the ground is more than 10° C. Ordinarily, in winter and early hot season, the fluctuations are found to be greatest between the hours 10 and 14. Analysing the observations according to wind-velocity of 4 ft. above ground, the mean rates of loss of heat measured on different occasions are given in Tables I and II expressed as the ratio of the rate of loss of heat to the temperature difference between ground and air at 4 ft. For purposes of general application, it is necessary to find a formula that would fit the observations with a reasonable degree of accuracy. In the analysis of the results of laboratory experiments made by different investigators M. Fishenden and O. A. Saunders[4] have given the following formula for the rate of heat transmission under conditions of natural convection from a horizontal surface with colder air above :—

$$H = 0{\cdot}38\ \theta^{5/4}\ \frac{\text{British Thermal Units}}{\text{ft.}^2\ \text{hr.}}$$ where θ is expressed in °F or

$$H/\theta = 0{\cdot}0036\ \theta^{\frac{1}{4}}\ \frac{\text{Cal.}}{\text{cm.}^2\text{min.}\ ^\circ\text{C.}} \quad \ldots \quad (3)$$

In (3), θ is the difference of temperature between the surface and the air outside the 'boundary' layer. The thickness of this layer is very variable when the wind-velocity approaches zero; under laboratory conditions with surfaces of limited area, it is 0·5 to 2 cm. In the open air, temperature continues to decrease for much greater heights, although the largest falls take place within the first 1 cm. In calculating H/θ according to (3) in Table I, the difference between the temperature of the ground (T_s) and the temperature of the air at 4 ft. (T_4) has been used. Very near the ground, the fluctuations of temperature are very large and the difficulty of defining the height also is great when the reference surface is as rough as the ground. It was found that in calm weather during the hot hours of the day, the temperature difference at about 1 cm. above ground was 1·5–1·6 times that at 4 ft. If in evaluating H/θ in column 3 of Table I, the difference of temperature between ground and air at 1 cm. had been used, the calculated values would have been still smaller. For purposes of calculation it appears that we can take the temperature of the air at 4 ft. level as the effective temperature of the air.

TABLE I.

θ °C.	H (observed)	H (calculated)
8·0	·066	·048
11·2	·086	·074
16·9	·184	·123
18·3	·148	·136

For forced convection, Jurges' laboratory experiments gave the following relation for the heat loss from a rough surface. The surfaces were copper plates 50 cm. square placed in alignment with the walls of a duct through which air was blown by means of a fan. Jurges' relation for rough surfaces was taken as representing the best approach to natural conditions.

For velocities $v < 5$ metres per sec., $H/\theta = \cdot0088 + \cdot0059\, v$ .. (4) where H is expressed in cal./cm.^{2} min., θ in degree Centigrade and v in metres/sec. The temperature and velocity of the air were presumably measured well outside the skin layer.

In Table II are grouped the mean values of H/θ for different values of v, measured in the open air at Poona and the values calculated according to

equation (4). The values of θ and v used in the calculation refer to air at 4 ft. above ground.

TABLE II.

v m/s	Mean H/θ observed	H/θ calculated according to (4)
0	·009	·0088
0·6	·016	·0123
0·9	·013	·0141
1·2	·018	·0159
1·5	·022	·0177
1·8	·020	·0194
2·4	·028	·0230
2·7	·027	·0247
3·0	·026	·0265
3·6	·031	·0300
3·9	·035	·0318
4·2	·033	·0336
4·8	·037	·0371

Velocities greater than 5 m./sec. were rarely experienced at 4 ft., but Jurges' relation for rough surfaces for these velocities takes the form

$$H/\theta = 0{\cdot}011\, v^{0{\cdot}78} \quad .. \quad .. \quad .. \quad (5)$$

K. Buttner, working in Tripolian Sahara, obtained the values 0·016 and 0·021 for H/θ for values of wind-velocity 0·8 to 1·5 m./sec. and 2 to 2·5 m./sec. at $\frac{1}{2}$ metre height above ground.

In Fig. 2 are plotted the curve of equation (4) and the individual observational values. It appears that on the whole, the equation gives an under-estimate for the actual amount of heat transferred by convection. We have, however, to remember the difference between the definitions of v and θ in the laboratory and open-air experiments. It is not easy to make a theoretically unexceptionable choice regarding the level at which v and θ

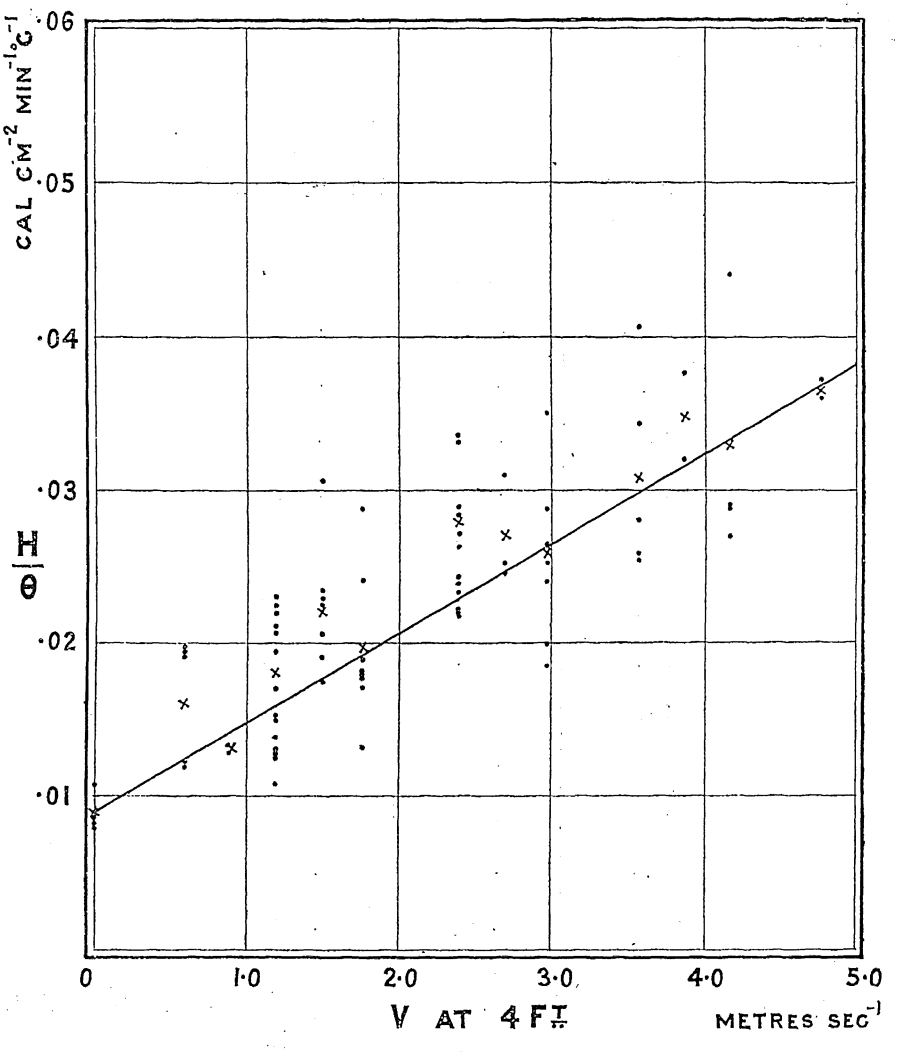


FIG 2.

should be measured for open-air experiments. Both these quantities vary rapidly with height immediately above the ground. The four-foot level* was chosen partly because it is well outside the region of largest fluctuations and partly because this is the level at which meteorological observations are usually taken, so that the results can later be extended to other places and conditions. To obtain a general estimate of the quantities involved, it appears that Jurges' formula can be employed, if θ and v are taken to refer

* Actually, the wind-velocity was measured at 1½ feet above ground by means of a cup anemometer and converted to that at 4 feet by means of the relation $v_{3/2}/v_4 = 0{\cdot}75$.

to 4 ft. level. Further measurements with an improved apparatus are projected for a more rigorous test of the applicability of the formula.

In Fig. 3 is shown a curve showing the variation of heat transmission by convection at different times on 2. 2. 35. The curve represents the values calculated by (4) and the marked points the measured values. The integrated loss of heat by convection on this day comes to be 175 calories. The

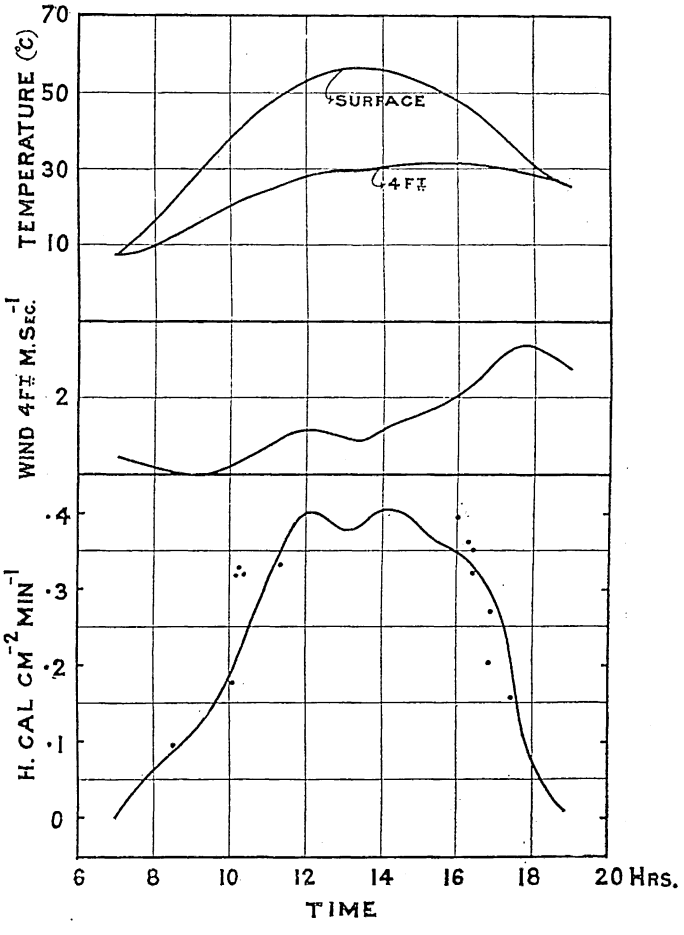


FIG. 3.

integrated heat loss on a number of days in the period February to May ranged from 175 to 340 cal. per day. In the region of sub-tropical highs in which Poona is situated in this season, we may take the average daily quantity of heat transferred by convection to the atmosphere on clear days to be about 250 calories. When the ground is dry, this will appear directly in the form of increase of temperature. When we are considering moist

ground or sea areas, the energy will go into the atmosphere partly in the form of latent energy of water-vapour. In dry land areas, the effect of this daily transference of heat to the lower atmosphere would be to raise the temperatures of the lower layers and set up a large lapse-rate in the first few kilometres of the atmosphere. Assuming that all the heat added by convection in one day goes to increase the temperature of the first 3 km. of the atmosphere, the resulting average increase of temperature will be

$$\frac{250}{0\cdot241\times1\cdot0\times10^{-3}\times10^{5}\times3} \text{ or } 3^{0}\cdot4\text{ C.}$$

Rise of temperature will, however, cause an increase of radiation of heat from the atmospheric layer and this, operating both day and night, would reduce the actual rise of temperature.

Cold air is sometimes brought down into lower latitudes during winter in the wake of western depressions, and this often spreads over the Deccan. The cold spells which follow are, however, brought to an end within two or three days when there is no fresh advent of cold air from the north. It is evident that the heat gained by the atmosphere by convection from the insolated ground will itself be sufficient to bring this about in two or three days.

In conclusion, the author desires to express his grateful thanks to the Director-General of Observatories for the facilities given and to Dr. K. R. Ramanathan and Dr. L. A. Ramdas for their guidance and help during the progress of this investigation. His best thanks are also due to Mr. G. Chatterji, Meteorologist-in-Charge, Upper Air Observatory, Agra, for kindly sending a reel of thin constantan strip which was used in this investigation. The experiments are being continued with improved apparatus.

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VARIATION IN THE NOCTURNAL RADIATION FROM THE SKY WITH ZENITH DISTANCE AND WITH TIME DURING THE NIGHT.

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and
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1. *Introduction.*

Measurements of the heat radiation received by unit area of a horizontal surface from the whole sky during clear nights at Poona, have been discussed by Ramanathan and Desai[1] and by Raman[2]. Ramanathan and Ramdas[3] showed that the expression $\frac{S}{\sigma T^4} = A - B \times 10^{-\gamma e}$ (where S is the radiation coming from the sky, T is the temperature of the air near the measuring instrument, σ is the Stefan-Boltzman constant, A, B and γ are other constants and e is the pressure of water vapour near the place of observation) obtained empirically by Angstrom can be derived from a consideration of the variation of the absorption coefficient of water vapour in different parts of the spectrum in the region of long waves. Hourly observations of the heat radiation coming from the night sky during selected clear nights at Poona have been discussed recently by Raman.[4] These observations show that the heat radiation from the water vapour in the atmosphere decreases with time during the night, the maximum value being obtained immediately after sunset and the minimum value just before sunrise. In the same paper, Raman has also discussed simultaneous hourly observations of the radiation from the night sky recorded at different levels at and near Poona and shown that the magnitude of the nocturnal variation of the sky radiation is maximum near the ground and decreases rapidly with height. These results find an explanation in the fact that the S_3 radiation which comes from the air layers nearest to the measuring instrument should depend upon the temperature of these layers [*vide* paper (3) above]. The nocturnal variation of the air temperature in these layers is maximum near the ground level and the magnitude of ΔS_3, the variation of the S_3 radiation, is found to be of the same order as that of the variation of the total radiation S for all the wave-

lengths taken together. The importance of the lower regions of the atmosphere in controlling the radiative phenomena which we are discussing, is brought out clearly by these results.

Further consideration of the whole problem indicated that it would be worth-while to study the variation of the nocturnal radiation with zenith distance* and with time during the night. Hourly measurements of the radiation from different regions of the sky and its variation during the course of the night were made during a few nights towards the end of the last clear season (April—May, 1936). It is felt that a brief account of the experimental method and the conclusions which could be drawn from these preliminary observations would prove to be of interest.

2. *Description of Apparatus.*

The nocturnal radiation is measured with the help of a Moll's Micro-thermopile and a Moll's Micro-galvanometer, both of which possess the high degree of sensitiveness and quickness of response required for detecting the variation in the intensity of the radiation from different parts of the sky. The thermopile is mounted inside a box and packed with cello-tex boards on all sides. The box is provided with a small aperture (which subtends an angle of about 10° at the surface of the thermopile) through which radiation passes into the receiver of the thermopile. The aperture can be closed by means of two shutters, one of which works inside at the box temperatures while the other works outside the box. The shutter inside the box is usually opened after and closed before the one outside while making the measurements. Fig. 1 shows a sketch of the thermopile box, with the two shutters and the aperture. T is a thermometer passing through a hole at the top of the box with its bulb in contact with the metal casing of the thermopile. The thermometer registers the temperature of the instrument and may be read from outside.

The thermopile so mounted was calibrated by exposing the sensitive element to the hemispherical radiation from a hollow radiator coated with carbon deposited from camphor smoke (see Fig. 2) and noting the deflections of the galvanometer when the surface of the radiator was maintained steadily at different temperatures.

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* The variation of atmospheric radiation with zenith distance has been discussed by Angstrom (*Astrophysical Journal*, 1914, 39, 1) and by W. H. Dines and L. H. G. Dines (*Mem. Roy. Met. Soc.*, 1927, 2) by using experimental methods different from the method used in the present investigation.

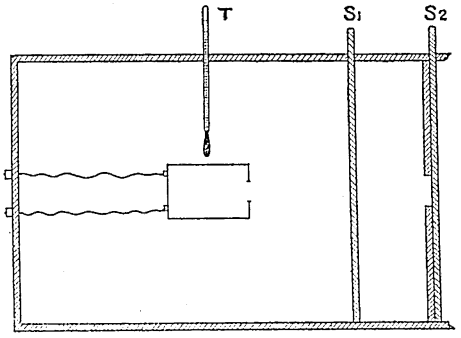


FIG. 1.
Thermopile.

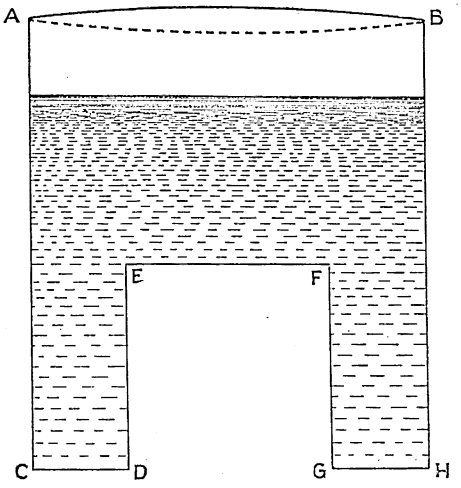


FIG. 2.
Radiator.

The thermopile was, after obtaining the calibration curve, taken outside into the open plot of the Central Agricultural Meteorological Observatory, for exposure to the different portions of the sky. When the aperture of the thermopile was facing upwards towards the zenith sky the deflection in the galvanometer was found to be steady and uninfluenced by any wind that might be playing round the instrument. For taking observations of the radiation from other angles, the instrument was tilted at the required angles in an azimuth opposite to that from which the wind, if any, was blowing. This precaution was found to be necessary and sufficient to obtain steady deflections in the galvanometer. The radiation from the sky at altitudes of 90° (vertical), 60°, 45°, 30°, 15° and 0° (horizontal) were recorded in the later experiments. Observations of the temperature of the air near the instrument and the pressure of water vapour in it were made with the help of an Assmann Psychrometer and the temperature of the thermopile was also read off each time the radiation observations were recorded. Observations of the total radiation coming from the whole sky were also recorded simultaneously with Angstrom's Pyrgeometer.

3. *Description of the Data.*

Attempts were made to record the hourly observations on a number of nights which were clear to start with. As the season was well advanced, however, on most of the nights alto-stratus or strato-cumulus clouds developed towards the morning. The preliminary observations recorded on the

25th April from the zenith sky and the fuller set of data recorded at different altitudes on the 2nd May 1936 were obtained from perfectly clear skies and the vapour pressure near the surface was also fairly steady. On the 30th April, however, there were traces of clouds at intervals; there was also a large change of vapour pressure at the surface but this did not alter the general trend of the results materially.

The data obtained on these three dates are discussed in the following pages.

TABLE I.

Measurements of Radiation from the zenith sky and other relevant meteorological observations taken during the night of the 25th April 1936.

Time in hours I. S. T.	Instrument Temperature °C.	Air Temperature near instrument °C.	Vapour pressure mm. of Hg.	Difference between temperature of 32°·8 C. and equivalent black body temperature of portion of sky concerned (ΔT)	Equivalent black body temperature T of portion of sky concerned °A.
1925	32·8	30·2	11·8	21·7	284·1
2010	30·8	28·7	12·1	21·8	284·0
2030	29·7	28·4	12·2	22·2	283·6
2100	28·8	27·8	12·7	22·5	283·3
2200	27·2	26·7	9·1	23·4	282·4
2300	25·5	25·7	13·1	24·4	281·4
2400	24·4	25·4	11·6	25·6	280·2
0100	23·1	23·8	13·3	27·2	278·6
0200	22·1	24·0	9·5	27·3	278·5
0300	21·5	23·0	9·3	28·0	277·8
0400	20·4	21·6	9·6	28·7	277·1
0500	19·5	21·4	7·7	29·0	276·8
0530	19·1	20·7	9·5	29·3	276·5

25th April 1936.—Table I gives the radiation observations recorded from the zenith sky on this date along with the other relevant data. Columns 1 to 4 of the table are self-explanatory. The deflections of the

galvanometer were corrected for the change of temperature of the thermopile from its initial value of 32°·8 C., using these corrected deflections the temperatures of a black body which, by exchange of radiation with the thermopile at 32°·8 C., would have caused these deflections were obtained from the calibration curve. We may call these black body temperatures the "equivalent black body temperatures" of the night sky. The differences between these temperatures from 32°·8 C. (ΔT) are given in column 5, while the equivalent black body temperatures themselves are given in the last column of the table. Fig. 3 shows the variation with time of the equivalent black body temperature of the zenith sky on this night. It will be seen that this temperature falls progressively as the night advances.

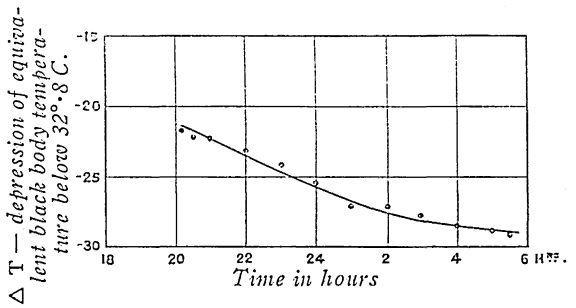


FIG. 3.

Nocturnal variation of the equivalent black body temperature of the zenith sky on 25–4–36.

30*th April* 1936.—On this day, the experiment was amplified so as to obtain simultaneous values of the equivalent black body temperatures of the sky at different vertical angles. A complete set of observations, at any hour, consisted in exposing the thermopile to the sky at the various vertical angles one after another. On the 30th April, the angles used were 90° (vertical), 60°, 45°, 30° and 15°. Table II gives the observations and the calculated data. The data presented in respect of each angle and the method of calculation are similar to those given in respect of the zenith sky for the 25th April in Table I. The values of ΔT in Table II are given as deviations from 34°.7 C., the initial temperature of the thermopile.

The curves in Fig. 4 (*a*) show the variation with time of the equivalent black body temperatures of the different altitudes of the sky mentioned against each curve. It will be observed that at each altitude the equivalent black body temperature shows a progressive fall with the advance of night, the fall becoming less rapid after midnight. The general characteristics of the variation at different altitudes are the same.

TABLE II.

Measurements of Radiation from the night sky from different altitudes and other relevant meteorological observations taken on the night of the 30th April 1936.

Time in hours I.S.T.	Instrument Temperature °C.	Air Temperature °C.	Vapour Pressure mm. of Hg.	Altitude – 90° (vertical)		Altitude—60°		Altitude—45°		Altitude—30°		Altitude—15°		Total radiation S from whole sky measured with Angstrom's pyrgeometer gm. cals./cm.²/min.
				Δ T below 34°·7 C.	T (°A)	Δ T below 34°·7 C.	T (°A)	Δ T below 34°·7 C.	T (°A)	Δ T below 34°·7 C.	T (°A)	Δ T below 34°·7 C.	T (°A)	
(1)	(2)	(3	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
1935	34.7	33·8	16·7	18·5	289·2									0·566
2000	34·3	33·2	16·0	19·0	288·7	17·0	290·7	15·5	292·2	13·0	294·7			0·563
2030	33·2	32·5	15·3	19·7	288·0	18·0	289·7	17·2	290·5	13·7	294·0	8·5	299·2	0·564
2100	32·6	32·0	14·7	20·4	287·3	19·0	288·7	17·6	290·1	15·0	292·7	9·1	298·6	0·553
2200	31·4	30·9	14·5	20·0	286·7	19·7	288·0	19·0	288·7	16·2	291·5	11·0	296·7	0·542
2300	29·5	29·1	12·5	23·5	284·2	22·5	285·2	20·5	287·2	17·6	290·1	13·2	294·5	0·524
2400	27·7	27·3	10·7	24·7	283·0	23·7	284·0	22·5	285·2	20·1	287·6	15·0	292·7	0·512
0100	25·4	25·2	9·6	26·0	281·7	24·5	283·2	23·2	284·5	20·3	287·4	15·7	292·0	0·501
0200	24·2	24·4	9·0	25·2	282·5	24·5	283·2	23·0	284·7	20·5	287·2	15·5	292·2	0·496
0300	22·7	23·2	8·7	27·0	280·7	26·0	281·7	24·5	283·2	22·0	285·7	17·0	290·7	0·503
0400	21·6	23·8	10·1	26·2	281·5	25·7	282·0	24·5	283·2	21·5	286·2	16·1	291·6	0·500
0500	22·0	23·8	8·1	26·7	281·0	24·5	283·2	24·5	283·2	21·5	286·2	17·5	290·2	0·503

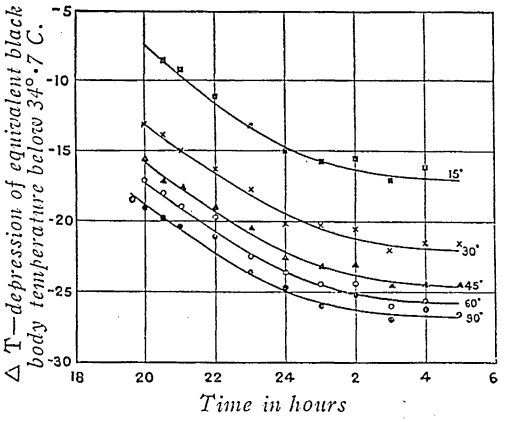


FIG. 4 (*a*).

Nocturnal variation of equivalent black body temperature at different altitudes of the sky on 30-4-1936.

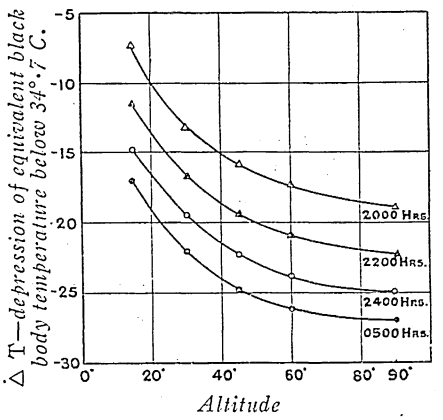


FIG. 4 (*b*).

Variation of equivalent black body temperature of the night sky with altitude at different hours on 30-4-1936.

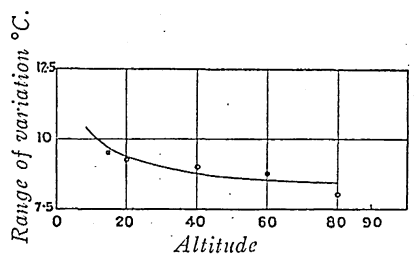


FIG. 4 (*c*).

Range of variation of equivalent black body temperature at different altitudes during the night of 30-4-1936.

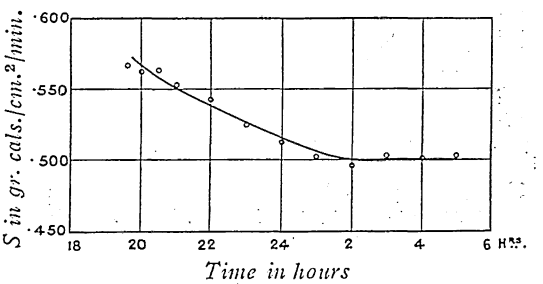


FIG. 4 (*d*).

Nocturnal variation of radiation S from whole sky as obtained from Pyrgeometer on 30-4-1936.

The information is also presented in a slightly different form in Fig. 4 (*b*) where the simultaneous values of the equivalent black body temperatures at the different altitudes of the sky (*viz.*, 90°, 60°, 45°, 30° and 15°) as obtained from the smooth curves of Fig. 4 (*a*) are plotted ; the hour to which each curve of Fig. 4 (*b*) refers is noted against it. These curves show that at any particular instant the equivalent black body temperature of the sky decreases as the vertical angle increases. From Fig. 4 (*b*) the values of the range of variation through the night of the equivalent black body temperatures at different altitudes of the night sky can be estimated. These values are plotted in Fig. 4 (*c*) against the vertical angle. It will be seen that the variation is minimum near the zenith and increases as one approaches the horizontal direction. In the last column of Table II, the values of S the total radiation

from the sky measured with Angstrom's Pyrgeometer are also given for comparison. These values are also shown diagrammatically in Fig. 4 (*d*).

2*nd May* 1936.—A further improvement of the experiment was made on this day inasmuch as observations were taken at all the altitudes from 0° to 90°. The observations of this date were obtained under ideal conditions as the skies were perfectly clear throughout the night. They are the best of the series obtained so far.

The data are given in detail in Table III and are also represented by means of the curves in Figs. 5 (*a*), (*b*) and (*c*) which fully confirm the results

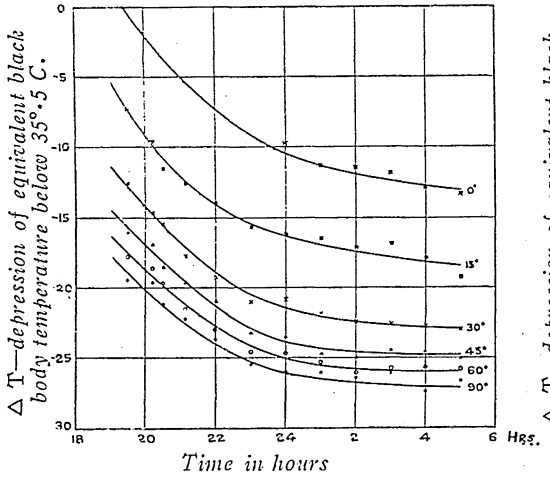


FIG. 5 (*a*).

Nocturnal variation of equivalent black body temperature at different altitudes of the sky on 2-5-1936.

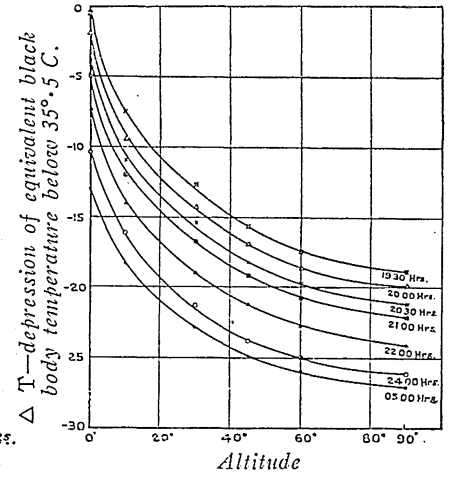


FIG. 5 (*b*).

Variation of equivalent black body temperature of the night sky with altitude at different hours on 2-5-1936.

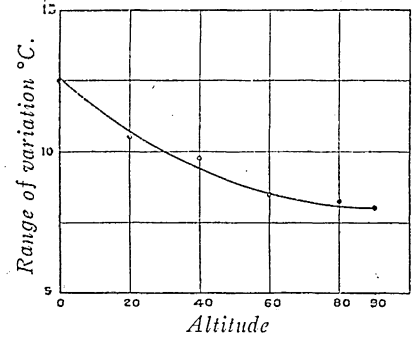


FIG. 5 (*c*).

Range of variation of equivalent black body temperature at different altitudes during the night of 2-5-1936.

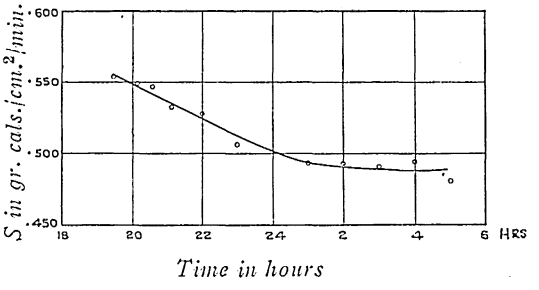


FIG. 5 (*d*).

Nocturnal variation of radiation S from whole sky as obtainad from Pyrgeometer on 2-5-1936.

TABLE III.

Measurements of Radiation from the night sky from different altitudes and other relevant meteorological observations taken on the night of the 2nd May 1936.

Time in hours I.S.T.	Instrument Temperature °C.	Air Temperature °C.	Vapour Pressure mm. of Hg.	Altitude 90° (vertical)		Altitude—60°		Altitude—45°		Altitude—30°		Altitude—15°		Altitude—0°		Total radiation S from whole sky measured with Angstrom's Pyrgeometer gm. cals./cm.²/min.
				Δ T below 35°·5 C.	T (°A)	Δ T below 35°·5 C.	T (°A)	Δ T below 35°·5 C.	T (°A)	Δ T below 35°·5 C.	T (°A)	Δ T below 35°·5 C.	T (°A)	Δ T below 35°·5 C.	T (°A)	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
1930	35·5	32·3	15·7	19·5	289·0	17·8	290·7	16·0	292·5	12·6	295·9	7·3	301·2			0·554
2010	33·0	30·8	16·5	19·6	288·9	18·6	288·9	16·9	291·6	14·7	293·8	9·6	298·9			0·549
2035	31·8	30·2	16·8	21·3	287·2	19·7	288·8	18·6	289·9	15·5	293·0	11·5	297·0			0·547
2110	30·4	29·0	15·3	22·2	286·3	21·5	287·0	19·7	288·8	17·8	290·7	12·6	295·9			0·532
2200	29·4	28·4	14·3	23·7	284·8	23·0	285·5	21·0	287·5	19·3	289·2	14·0	294·5			0·527
2300	27·8	28·0	12·0	25·5	283·0	24·6	283·9	23·2	285·3	21·0	287·5	15·7	292·8			0·506
2400	27·2	24·2	11·8	26·0	282·5	24·7	283·8	23·5	285·0	20·8	287·7	16·2	292·3	9·8	298·7	..
0100	25·6	25·8	12·8	26·0	282·5	25·3	283·2	24·8	283·7	21·8	286·7	16·5	292·0	11·2	297·3	0·494
0200	25·0	25·2	13·7	26·4	282·1	26·0	282·5	25·0	283·5	22·4	286·1	17·1	291·4	11·4	297·1	0·493
0300	24·6	24·8	14·2	26·0	282·5	25·8	282·7	24·5	284·0	22·5	286·0	16·9	291·6	11·7	296·8	0·490
0400	24·1	24·6	12·9	27·4	281·1	25·7	282·8	24·5	284·0	22·6	285·9	17·9	290·6	12·8	296·5	0·494
0500	23·2	23·0	11·4	26·6	281·9	25·8	282·7	25·0	283·5	23·0	285·5	19·3	289·2	13·4	295·1	0·480

of the 30th April. The values of ΔT in Table III are given as deviations from 35°·5 C., the initial temperature of the thermopile.

The intensity of the total radiation S from the night sky as measured with an Angstrom's Pyrgeometer at different hours on the night of the 2nd May 1936 are given in the last column of Table III, and shown diagrammatically in Fig. 5 (*d*).

From the data discussed above, two main conclusions emerge, *viz.*,

(i) there is a decrease with progress of night in the intensity of radiation coming from the different zones of the night sky, and

(ii) the decrease is maximum in the radiation coming from the horizontal direction and minimum from the zenith sky.

The first result is in agreement with the results discussed in the earlier paper (*vide* paper 4, *loc. cit.*) where it has been shown that there is a decrease with time in the nocturnal radiation from the night sky as a whole.

Regarding the second result, we should remember that the water vapour content of the atmosphere decreases rapidly with height and that the layers of equal water vapour content are horizontal. So far as the S_3 radiation is concerned, the radiation from a horizontal or vertical direction will be coming from the air layers in the immediate neighbourhood of the instrument; also, the variation of S_3 with time will be greater in a horizontal direction than in a vertical direction, because, the nocturnal cooling decreases with height. When we come to the S_2 radiation, however, we see that this radiation from a vertical direction will be coming from a region of the upper atmosphere which undergoes little or no cooling during the night. The S_2 radiation from a horizontal direction comes from air layers which are relatively nearer the instrument. As these layers experience the largest fall of temperature during the night, it follows that the S_2 radiation will also undergo a decrease with time during the night. The result is that in the horizontal direction both S_2 and S_3 vary whereas, in the vertical direction, S_2 does not undergo any change. We shall consider these details more fully in a later paper. The mean equivalent black body temperature of the night sky, as a whole, can be calculated in a simple manner from the zonal distribution of temperature and the results compared with the measurements of S with Angstrom's Pyrgeometer. This will be taken up after collecting more observational data during the coming winter.

Summary.

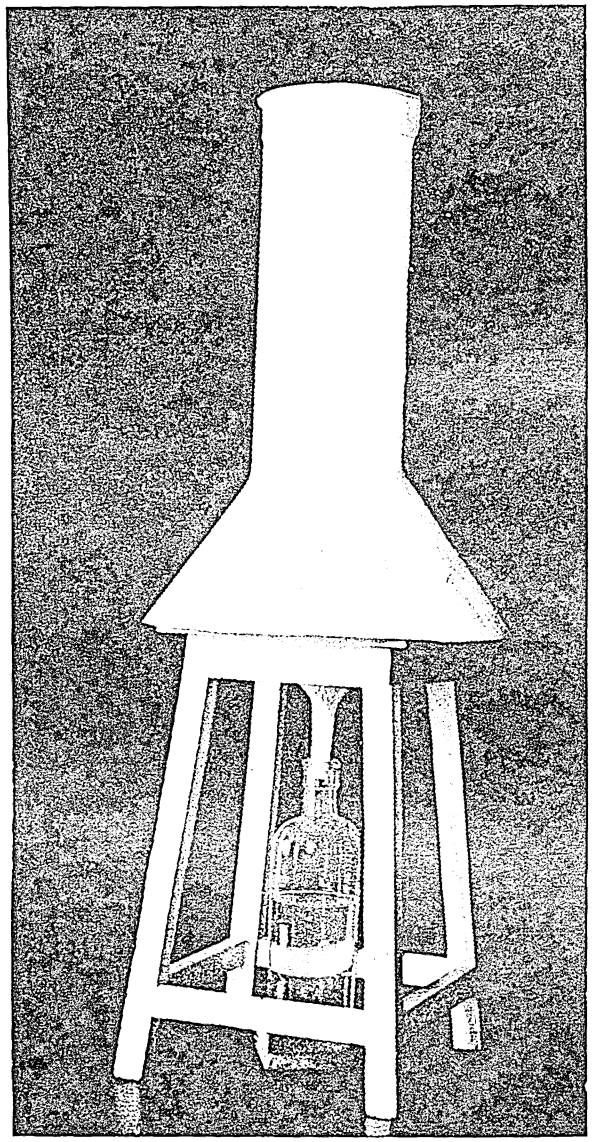
The hourly variation of the heat radiation coming from different altitudes of the night sky was measured on three nights in April and May 1936 with a Moll's Micro-galvanometer and a Micro-thermopile provided with a

small aperture. These observations show that the nocturnal cooling of the radiating air layers as shown by the decrease in the equivalent black body temperature of the sky is maximum for altitude zero (*i.e.*, horizontal) and minimum for altitude 90° (*i.e.*, zenith).

The authors have great pleasure in thanking the Director-General of Observatories for providing necessary facilities for the investigation.

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Portable drain-gauge.

AGRICULTURAL METEOROLOGY

STUDIES ON SOIL-MOISTURE IN RELATION TO MOISTURE IN THE SURFACE LAYERS OF THE ATMOSPHERE DURING THE CLEAR SEASON AT POONA

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(With Plate LXVI and ten text-figures)

Introduction

In a previous communication* [Ramdas and Katti, 1934,[1]] the phenomenon of the evaporation of moisture from a soil surface containing only hygroscopic water and the reverse phenomenon during night, *viz.*, the absorption of moisture from the air layers near the ground by the desiccated soil surface, were shown to exert a controlling influence on the distribution of moisture with height in the air layers. From observations of the moisture contents of the soil surface and of the air at different levels above ground it was found that, during the "evaporating regime" (during day), the pressure of water vapour decreased with height, whereas, during the "absorbing regime" (at night), the vapour pressure increased with height. In the preliminary studies which have been discussed in the above paper the observations were taken only twice daily with the local soil, *viz.*, at sunrise and at sunset. With a view to study the diurnal variation in the moisture content two-hourly measurements were made with representative soils from different parts of the country, the soils being exposed under identical conditions in the Agricultural Meteorological Observatory at Poona. Such measurements were conducted during the summer of 1934 as well as during the winter of 1935. Besides these, measurements of the moisture content of the surface layers of the soil in the bare ground of the Agricultural Meteorological Observatory were also made in 1935. Experiments on the absorption of moisture by dry soils and measurements of various related physical properties of typical soils were also made in the laboratory about the same time. In all these investigations the meteorological aspect has been kept in the fore-front and the soils have been used as they occur, *i.e.*, without separating them into their components by mechanical or chemical analysis. These results are discussed in the following sections :

* "Preliminary studies on soil-moisture in relation to moisture in the surface layers of the atmosphere during the clear season at Poona" by Ramdas, L. A. and Katti, M. S., *Indian Journal of Agricultural Science*, Vol. IV, part 6, 1934. (This paper will be referred to as paper 1 in the following pages.)

Section I

Experiments on the evaporation and absorption of water vapour by different soils

1. Two-hourly observations of the moisture contents of a few soils during the summer of 1934 (23rd May to 2nd June 1934)

After realising from the preliminary experiments discussed in paper 1 that the results indicated an interesting line of work, steps were taken (1) to pursue work with different types of soils and (2) to commence observations several times daily so as to study the diurnal variation in the moisture contents in greater detail. Although the season was well advanced and the simple climate of winter had given place to one of the sea-breeze type, there was a spell of clear weather and it was considered worth while to start comparative observations in order to see how, under similar meteorological conditions, soils differed from one another.

The observations were begun at the Agricultural Meteorological Observatory with Poona black cotton soil at 0600 hrs. on the 23rd May 1934 ; on the morning of the 25th, samples of alluvial soil from Sakrand (in Sind) were added ; on the morning of the 1st June 1934, samples of quartz powder, brown Dharwar schist and red laterite were also included. The two-hourly observations on the soil samples were continued up to 0600 hrs. on the 2nd June after which they were discontinued owing to the onset of cloudy weather.

During the above period (23rd May to 2nd June) the skies were clear but the simple climate of winter had changed to one of the " afternoon sea-breeze " type. Ordinarily, during calm weather in winter, the air sample over Poona does not change materially during the day or, often, during a series of days. The convective winds during such days cause mixing of the air layers in the vertical direction. In February and later months of the clear season the westerly sea-breeze begins to arrive at Poona about sunset. The time of arrival becomes earlier as the season advances. This breeze which replaces the land air has a higher moisture content. The sea-breeze penetrates inland slowly, dies down by midnight and later remains stagnant over the country until, after sun-rise on the next morning, the diurnal convection sets in and mixes up the shallow layer of moist air with the reservoir of dry air at the higher levels. During the sea-breeze season, *viz.*, part of February, March, April and May, the dry land air holds its sway during day time but is regularly displaced by sea-air during the night. The effect of this is seen in the psychrometric data taken at the maximum and minimum temperature epochs. These show higher vapour pressures during the night and until the next morning up to about 8 A.M., than during the day time after the convective winds have set in. During the earlier months of the season which are free from sea-breeze the mean vapour pressure is practically the same day and night. As already explained in paper 1, both during the non-sea-breeze and the sea-breeze portions of the clear season the vapour pressure increases with height during the night and decreases with height during the day.

TABLE I

Time	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700
Weight of Poona soil in grms. (Mean for 23-31 May 1934).	60·751	60·676	60·554	60·355	60·017	59·709	59·370	59·159	59·021	58·961	58·973	59·038
Weight of Sakrand soil in grms. (Mean for 25-31 May 1934).	60·435	60·379	60·321	60·256	60·197	60·144	60·104	60·074	60·053	60·041	60·034	60·043
Temperature °C. (Soil surface) . . .	22·5	27·5	35·1	44·1	52·0	57·5	60·5	61·1	59·4	56·2	51·6	45·8
Air temperature (0·3″) °C.	22·6	25·0	27·9	31·8	35·6	38·5	40·8	42·3	42·9	42·7	41·7	38·6
Air temperature °C. (one ft.) . . .	22·9	24·7	27·2	30·2	33·4	35·4	36·9	38·0	38·6	38·6	38·0	36·4
Wind speed at 1′-6″ (miles per hour) . .	4·7	5·2	5·8	6·2	6·9	7·4	8·1	8·9	8·9	8·9	9·1	9·2
Vapour pressure (0·3″) in mm. of Hg. . .	14·5	15·2	15·6	15·4	14·7	14·3	13·3	13·3	12·2	11·6	11·3	12·2
Vapour pressure (4 ft.) in mm. of Hg. . .	14·6	14·7	14·6	14·1	13·5	13·0	12·3	11·4	10·6	10·5	10·5	11·6
Humidity per cent (0·3″)	71	64	56	43	34	28	23	21	19	18	20	24

Time	1800	1900	2000	2100	2200	2300	2400	0100	0200	0300	0400	0500
Weight of Poona soil in grms. (Mean for 23-31 May 1934).	59·185	59·383	59·621	59·837	60·003	60·148	60·265	60·379	60·475	60·557	60·631	60·693
Weight of Sakrand soil in grms. (Mean for 25-31 May 1934).	60·061	60·089	60·123	60·168	60·199	60·226	60·253	60·276	60·301	60·321	60·342	60·361
Temperature °C (Soil surface) . . .	39·6	34·4	31·8	29·9	28·4	27·1	26·3	25·5	24·7	24·0	23·4	22·9
Air temperature (0·3″) °C.	34·4	31·6	29·1	27·4	26·1	25·4	24·8	24·4	24·2	23·7	23·2	22·9
Air temperature °C. (one ft.) . . .	33·6	31·1	28·8	27·2	26·0	25·3	24·8	24·4	24·1	23·8	23·5	23·3
Wind speed at 1′-6″ (miles per hour) . .	9·3	8·9	8·1	7·3	6·7	6·4	5·7	4·9	5·1	5·0	4·8	4·4
Vapour pressure (0·3″) in mm. of Hg. . .	13·3	14·1	14·6	15·3	15·6	15·4	15·0	15·2	15·2	15·2	15·2	15·2
Vapour pressure (4 ft.) in mm. of Hg. . .	13·0	13·8	15·0	15·9	16·3	16·1	15·9	15·8	15·8	15·6	15·4	15·4
Humidity per cent (0·3″) . . .	32	40	48	56	61	63	64	66	67	69	72	70

The soil samples, weighing about fifty grammes each, were exposed in small aluminium vessels having a cross-section of 30 sq. cm. The vessels were embedded in the ground so as to bring the level of the soils inside flush with that of the soil outside. In the case of the soils of Poona and Sakrand, the samples were exposed in duplicate ; only one sample each of the other soils was used. The two-hourly observations consisted of the following measurements :—

(*a*) the weight of each soil sample (the vessels were kept tightly covered during weighing which was done quickly on a good physical balance),

(*b*) air temperature, humidity and vapour pressure at several levels starting from the soil surface (with an Assmann psychrometer),

(*c*) wind speeds at $1\frac{1}{2}$ ft. and 6 ft.,

(*d*) soil temperature at the surface of the soil, and

(*e*) the intensity of the total radiation from the sun and the sky from the records of the Moll solarigraph.

In studying these data it was convenient to plot the observations against the actual times at which they were made and from these curves to read off the hourly values. Table I gives the mean hourly weights of the Poona soil (mean for the period 23rd to the 31st May 1934) and the Sakrand soil (mean for the period 25th to the 31st May 1934). The hourly variations shown by the duplicate samples agree very closely and the figures in the table are the averages obtained from the duplicate samples. The mean hourly data of the following meteorological factors are also given in Table I :—

(*i*) soil-surface temperature in °C.,

(*ii*) air temperature at 0·3″ above the ground,

(*iii*) air temperature at 1 ft. above the ground,

(*iv*) the percentage humidity at 0·3 in. and the pressure of water vapour in mm. of Hg. of the air at 0·3″ and 4 ft. above the ground, and

(*v*) the velocity of wind at 1 ft. 6 in. above the ground (in miles per hour).

The hourly data bring out the characteristics of the phenomena under consideration in much greater detail than the data recorded at sunrise and at sunset and given in Table VII of paper 1. It may be noted that the soils have their *minimum* moisture content about the epoch of maximum temperature and their *maximum* moisture content at the epoch of minimum temperature. The results are easier to visualise when represented diagrammatically (Fig. 1). The epochs of *maximum air temperature*, *minimum saturation* of air with water vapour (humidity per cent) and *minimum water vapour content* in the air (this would be maximum water vapour content during days of no sea-breeze, *e.g.*, December, January, when we deal with the same air samples) occur practically at the same time as the epoch of *minimum* moisture content of the soil samples. During months with no sea-breeze the maximum wind velocity would also have occurred about the same time.

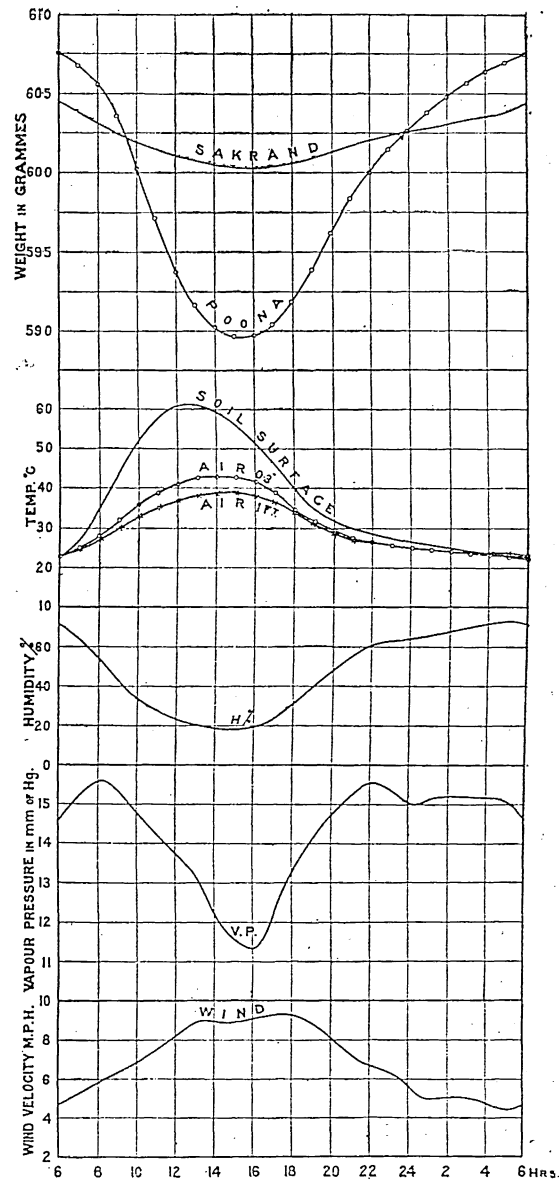

WEIGHT IN GRAMMES
610
605
600
595
590
SAKRAND
POONA
TEMP. °C
60
50
40
30
20
10
SOIL SURFACE
AIR 9h.
AIR 3h.
HUMIDITY %
80
60
40
20
0
H
VAPOUR PRESSURE IN mm OF Hg.
15
14
13
12
11
10
V.P.
WIND VELOCITY M.P.H.
10
8
6
4
2
WIND
6 8 10 12 14 16 18 20 22 24 2 4 6 HRS.

Fig. 1.

The epoch of *maximum moisture content* of the soil samples coincides with the epoch of minimum temperature and maximum saturation of the air with water vapour. As already pointed out, the air layer nearest to the ground would have a smaller water vapour content than the layers higher up in the early morning, but this is somewhat masked by the disturbance due to sea-breeze during the night. It is significant that the variation of moisture content of the soil is in phase with the variation of the air temperature and humidity percentage rather than the soil surface temperature (which closely follows the altitude of the sun and has a maximum value when the sun is over-head).

The other interesting fact which may be observed from Fig. 1 is that the diurnal variation of moisture in the Poona soil is more than four times that of the soil from Sakrand [Ramdas and Katti, 1934,[2]]. The very first day's results suggested that each soil type may show a characteristic diurnal variation. This expectation has been borne out by the observations recorded in June 1934 (0600 hrs. of 1st June 1934 to 0600 hrs. of 2nd June 1934) and the later observations made during the clear season October 1934 to May 1935. Fig. 2 shows the hourly variation of the moisture contents of soils from Poona, Dharwar and Sakrand, a sample of red laterite and a sample of quartz powder respectively from 0600 hrs. of 1st June 1934 to 0600 hrs. of 2nd June 1934. The sample of quartz powder did not show any variation of weight whereas the other soils showed different diurnal variations in their weights. The maximum weight of the soil (in the morning) when its moisture content is maximum and the minimum weight (in the afternoon) when its moisture content is minimum are given in Table II.

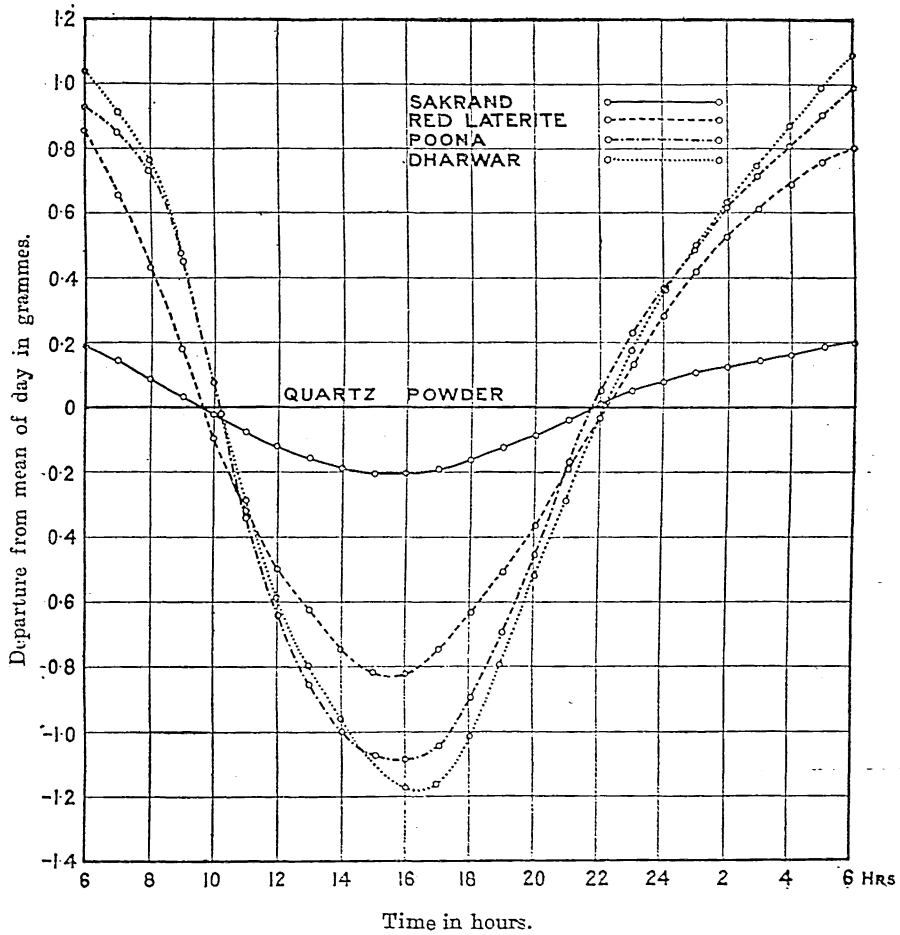


Fig. 2. Hourly variation of moisture-content of five different soils (0600 hours of 1st June 1934 to 0600 hours of 2nd June 1934).

TABLE II

Name of soil	Maximum weight (morning) grms.	Minimum weight (afternoon) grms.	Diurnal range of moisture content grms.
Quartz powder	60·610	60·610	0·000
Sakrand soil	60·575	60·160	0·415
Red laterite	61·080	59·390	1·690
Poona soil (black cotton)	61·400	59·350	2·050
Dharwar (brown schist)	61·450	59·220	2·230

2. Diurnal variation of moisture in eight soils (0600 hrs. of the 22nd to 0600 hrs. of the 23rd January 1935)

It was possible to collect more soil samples from different parts of the country and study the diurnal variations in their moisture contents in January 1935. The experimental procedure was similar to that described in the previous sub-section. Table III gives the particulars regarding the soil samples used.

TABLE III

Name of soil	Colour of the soil	Area of cross-section of vessels used for exposing the samples	Mean weight of soil in grms.
Poona	Black	12·6 sq. cm.	30·16
Sholapur	Black	,,	30·46
Hagari	Dark	,,	29·75
Ranchi	Red	,,	29·90
Jhelum	Reddish grey	,,	30·31
Bangalore	Red	,,	30·46
Pusa	Grey (alluvial)	,,	29·75
Lyallpur	Dark-grey	,,	30·33

The hourly weights of these soil samples, when exposed to identical weather conditions from 0600 hrs. of the 22nd to 0600 hrs. of the 23rd January 1935, as well as their departures from the respective mean weights are given in Table IV. Fig. 3 which shows these results diagrammatically confirms the features shown by Fig. 2.

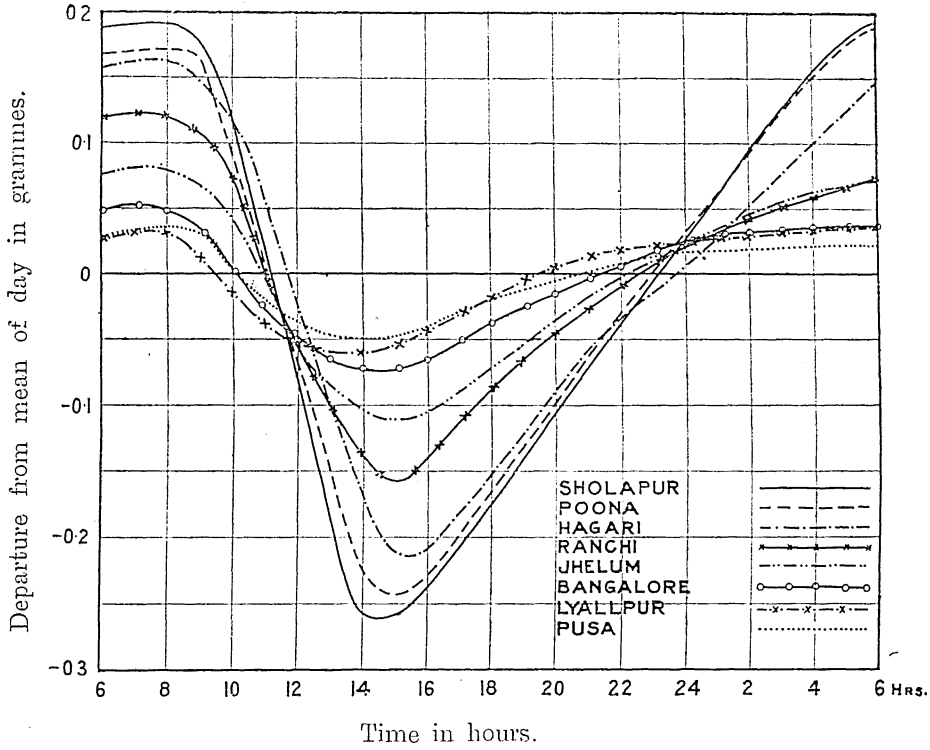


Fig. 3. Hourly variation of moisture-content of eight different soils.

On this day there were traces of clouds in the afternoon which decreased rapidly towards the evening, the night being practically clear. The hourly march of soil temperature, air temperature, humidity percentage, pressure of water vapour, wind and cloudiness are shown in Fig. 4. Apart from the slight cloudiness in the afternoon the day was one of the winter type without any sea-breeze. The stratification of the air layers at night (coldest air being a few inches above the ground and then temperature increasing with height) was undisturbed. The reversal of the vapour pressure gradient may be seen in Fig. 4. The nocturnal desiccating influence of the soil on the air layers near it is also clearly seen.

Temperature in °C. of soil surface and of air at 0·3″ and 1′ above surface.

Humidity percentage at 0·3″ above ground.

Vapour pressure (mm. of Hg.) near surface of ground and at 6 ft. above ground.

Wind velocity m.p.h.

Duration of clear skies. If sunshine recorder shows clear skies during the whole of an hour the value is 1·0, if cloudy the value is 0·0.

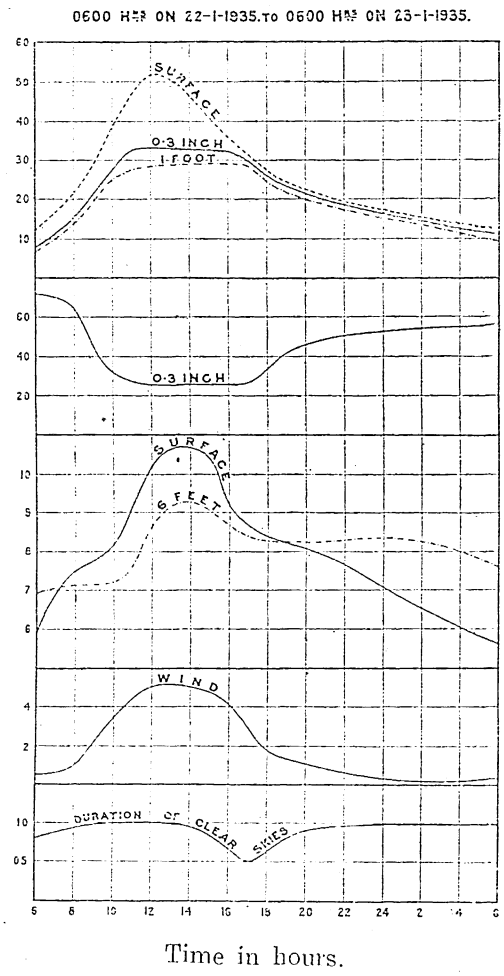


Fig. 4. Hourly variation of meteorological factors (0600 hours of 22nd January 1935 to 0600 hours of 23rd January 1935).

TABLE IV

Time in hours (I. S. T.)	Poona soil		Sholapur soil		Hagari soil		Ranchi soil (Plot 4)		Jhelum soil (305/1930)		Bangalore soil		Pusa soil		Lyallpur soil	
	Weight in grms.	Departure from mean of day	Weight in grms.	Departure from mean of day	Weight in grms.	Departure from mean of day	Weight in grms.	Departure from mean of day	Weight in grms.	Departure from mean of day	Weight in grms.	Departure from mean of day	Weight in grms.	Departure from mean of day	Weight in grms.	Departure from mean of day
0600	54·705	0·161	59·115	0·186	60·395	0·156	56·176	0·119	56·745	0·076	64·660	0·049	68·443	0·028	58·876	0·027
0700	54·710	0·166	59·120	0·191	60·400	0·161	56·180	0·123	56·750	0·081	64·665	0·054	68·446	0·031	58·880	0·031
0800	54·710	0·175	59·120	0·191	60·400	0·161	56·177	0·120	56·750	0·081	64·660	0·049	68·455	0·040	58·880	0·031
0900	54·710	0·166	59·105	0·176	60·385	0·146	56·165	0·108	56·738	0·069	64·648	0·037	68·451	0·036	58·862	0·013
1000	54·635	0·091	59·045	0·116	60·355	0·116	56·133	0·076	56·714	0·045	64·615	0·004	68·416	0·001	58·835	—0·014
1100	54·560	0·016	58·955	0·026	60·290	0·051	56·060	0·003	56·666	—0·003	64·585	—0·026	68·395	—0·020	58·805	—0·044
1200	54·482	—0·062	58·850	—0·079	60·214	—0·025	56·000	—0·057	56·612	—0·057	64·564	—0·047	68·380	—0·035	58·793	—0·056
1300	54·395	—0·149	58·745	—0·184	60·145	—0·094	55·961	—0·096	56·585	—0·084	64·546	—0·065	68·368	—0·047	58·790	—0·059
1400	54·320	—0·224	58·670	—0·259	60·080	—0·159	55·920	—0·137	56·564	—0·105	64·540	—0·071	68·368	—0·047	58·790	—0·059
1500	54·300	—0·244	58·670	—0·259	60·030	—0·209	55·900	—0·157	56·558	—0·111	64·540	—0·071	68·368	—0·047	58·799	—0·050
1600	54·314	—0·230	58·700	—0·229	60·033	—0·206	55·920	—0·137	56·567	—0·102	64·546	—0·065	68·377	—0·038	58·811	—0·038
1700	54·347	—0·197	58·726	—0·203	60·061	—0·178	55·955	—0·102	56·582	—0·087	64·561	—0·050	68·386	—0·029	58·820	—0·029
1800	54·380	—0·164	58·756	—0·173	60·090	—0·149	55·970	—0·087	56·600	—0·069	64·579	—0·032	68·395	—0·020	58·829	—0·020
1900	54·416	—0·128	58·790	—0·139	60·120	—0·119	55·992	—0·065	56·615	—0·054	64·591	—0·020	68·402	—0·013	58·844	—0·005
2000	54·455	—0·089	58·826	—0·103	60·154	—0·085	56·012	—0·045	56·636	—0·033	64·603	—0·008	68·410	—0·005	58·856	—0·007

TABLE IV—*contd.*

Poona soil			Sholapur soil		Hagari soil		Ranchi soil (Plot 4)		Jhelum soil (305/1930)		Bangalore soil		Pusa soil		Lyallpur soil.	
Time in hours (I. S. T.)	Weight in grms.	Departure from mean of day	Weight in grms.	Departure from mean of day	Weight in grms.	Departure from mean of day	Weight in grms.	Departure from mean of day	Weight in grms.	Departure from mean of day	Weight in grms.	Departure from mean of day	Weight in grms.	Departure from mean of day	Weight in grms.	Departure from mean of day
2100	54·500	—0·044	58·868	—0·061	60·187	—0·052	56·030	—0·027	56·654	—0·015	64·615	0·004	68·415	0·000	58·862	0·013
2200	54·525	—0·019	58·904	—0·025	60·202	—0·037	56·048	—0·009	56·666	—0·003	64·620	0·009	68·428	0·013	58·868	0·019
2300	54·551	0·007	58·934	0·005	60·220	—0·019	56·066	0·009	56·681	0·012	64·630	0·019	68·428	0·013	58·871	0·022
2400	54·575	0·031	58·964	0·035	60·250	0·011	56·078	0·021	56·693	0·024	64·640	0·029	68·431	0·016	58·871	0·022
0100	54·600	0·056	58·988	0·059	60·268	0·029	56·090	0·033	56·705	0·036	64·640	0·029	68·434	0·019	58·877	0·028
0200	54·626	0·082	59·021	0·092	60·295	0·056	56·099	0·042	56·717	0·048	64·642	0·031	68·434	0·019	58·880	0·031
0300	54·655	0·111	59·054	0·125	60·316	0·077	56·108	0·051	56·726	0·057	64·642	0·031	68·435	0·020	58·884	0·035
0400	54·685	0·141	59·084	0·155	60·340	0·101	56·120	0·063	56·732	0·063	64·648	0·037	68·436	0·021	58·886	0·037
0500	54·710	0·166	59·102	0·173	60·364	0·125	56·126	0·069	56·738	0·069	64·649	0·038	68·438	0·023	58·886	0·037
0600	54·722	0·178	59·120	0·191	60·385	0·146	56·138	0·081	56·742	0·073	64·649	0·038	68·440	0·025	58·886	0·037
Mean of day	54·544		58·929		60·239		56·057		56·669		64·611		68·415		58·849	

We may now combine the results of Tables I and IV and calculate the moisture variation index of different types of soils (diurnal range of moisture content expressed as a ratio of the diurnal range of the Poona soil). The values of this coefficient are given in Table V for all the soils which have been experimented with.

TABLE V

Name of soil	Moisture variation index (Poona=1)
Poona black cotton soil	1·00
Dharwar black cotton soil	1·10
Sholapur black soil	1·04
Hagari	0·86
Red laterite	0·81
Ranchi	0·65
Jhelum	0·44
Bangalore	0·29
Pusa (alluvial)	0·20
Lyallpur (alluvial)	0·21
Sakrand (alluvial)	0·19
Quartz powder	0·00

The above table shows that the black cotton soils undergo the maximum diurnal variation of moisture content owing to the loss of water by evaporation during the day and gain by absorption from the air during the night. The brown and red soils come next. The alluvial soils from the Indo-Gangetic as well as the Sind areas show a diurnal variation which is only a fifth of that of the black cotton soils. The sample of quartz powder comes at the bottom of the list with no variation. It is indeed remarkable that soils from places at large distances apart show very similar features so long as they belong to the same soil group [Ramdas and Katti, 1935,[1]]. We shall discuss this point at greater length in a later section.

3. Diurnal range of the moisture content of Poona soil as estimated from actual samples taken daily from the soil surface during the period 22nd January 1935 to 5th March 1935

The hourly variation of the moisture content of soil samples discussed in the two previous sub-sections clearly shows that the epochs of maximum and minimum water contents coincide with the epochs of minimum and maximum air temperature respectively. In Table VIII of paper 1 we have indicated the results of earlier estimations of the moisture content of the soil samples taken from the surface at sunrise and at sunset respectively. In view of the more precise information regarding the epochs of maximum and minimum moisture contents of the soil (which shows that the time of minimum moisture content is much earlier than sunset time) available from the investigations described above, it was considered

worth while to make daily estimations of the moisture contents of soil samples taken from the surface of the bare soil of the Agricultural Meteorological Observatory at 0630 hrs. and 1530 hrs. I. S. T. respectively in order to find out how the diurnal range of the moisture-content varied from day to day. Such daily estimations were made from the 22nd January to the 5th March 1935. The results are given in Table VI. The moisture-contents are here expressed as percentages of the weight of the dry soil. The differences between these percentages are quite large and systematic. The average moisture content in the morning during the whole period is 7·79 per cent whereas that in the afternoon is 3·80 per cent and the difference of nearly four per cent shows how large is the diurnal variation. This diurnal variation is in agreement with the value obtained by experiments with the soil inside a vessel (Tables II and IV), thus showing that the results of all these experiments support each other satisfactorily.

TABLE VI

Moisture percentage in samples from surface soil taken in the morning and evening at about 6-30 A.M. and 3-30 P.M. respectively

Date	A.M.	P.M.	Date	A.M.	P.M.
22nd Jan. 1935	9·81	5·20	12th Feb. 1935	6·95	3·40
23rd ,, 1935	9·12	5·07	13th ,, 1935	7·12	3·55
24th ,, 1935	8·78	3·82	14th ,, 1935	7·83	3·20
25th ,, 1935	9·54	5·48	15th ,, 1935	7·04	3·06
26th ,, 1935	9·23	4·91	16th ,, 1935	6·81	3·22
27th ,, 1935	8·94	5·06	17th ,, 1935	6·78	2·93
28th ,, 1935	9·42	5·23	18th ,, 1935	6·91	3·30
29th ,, 1935	9·45	5·84	19th ,, 1935	7·35	3·31
30th ,, 1935	8·53	4·21	20th ,, 1935	7·22	2·81
31st ,, 1935	8·84	5·32	21st ,, 1935	6·81	3·64
1st Feb. 1935	9·01	4·92	22nd ,, 1935	7·00	3·25
2nd ,, 1935	8·62	4·00	23rd ,, 1935	6·92	2·89
3rd ,, 1935	8·53	4·12	24th ,, 1935	6·65	2·54
4th ,, 1935	8·04	3·55	25th ,, 1935	7·21	3·12
5th ,, 1935	7·85	4·05	26th ,, 1935	7·13	3·32
6th ,, 1935	8·13	4·93	27th ,, 1935	7·55	3·34
7th ,, 1935	7·32	3·94	28th ,, 1935	7·08	3·26
8th ,, 1935	7·52	3·41	1st Mar. 1935	6·98	3·15
9th ,, 1935	6·84	3·23	2nd ,, 1935	7·35	2·94
10th ,, 1935	7·21	3·30	3rd ,, 1935	7·21	3·30
11th ,, 1935	7·32	3·89	4th ,, 1935	7·43	3·12
			5th ,, 1935	7·51	3·43

Fig. 5 gives the hourly values of the moisture content of the surface soil as estimated on 22nd January 1935. The similarity of the hourly march as shown by this figure to that seen in Figures 1, 2 and 3 is quite striking.

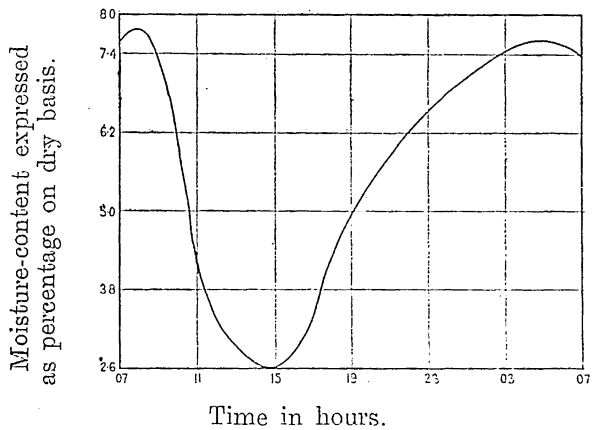


Fig. 5. Hourly variation in the moisture-content of the surface soil (in the open field) on 22nd January 1935.

4. Diurnal variation in the moisture-content of Poona soil in relation to its depth below the soil surface

We have established the following facts in the previous sub-sections : —

(1) there is a conspicuous exchange of moisture between the soil surface and the air layers above it,

(2) the intensity of this exchange is a characteristic property of each soil, and

(3) the epochs of maximum and minimum moisture contents of the soil coincide with those of minimum and maximum temperatures respectively.

In the experiments with samples kept in vessels the soil and the air layers form the two components in the system. Under actual field conditions, however, we have to investigate whether the layers below the surface play any important part in the moisture balance at the surface during clear weather. The problem is much simplified by the fact that, in the Bombay-Deccan, there is no water table which would affect the soil layers near the surface, because the surface layers are resting above hard rock or *murram* and the water table is several feet below. The question whether the soil immediately below the surface makes any measurable contribution of moisture to the surface during the day can be settled easily by taking samples from different depths at intervals during the day and estimating their moisture contents. If there is a significant diurnal variation of the moisture contents at these depths, then it will be necessary to conclude that these layers do take part in the moisture balance at the surface.

TABLE VII

Diurnal variation of soil-moisture (per cent on dry basis) at different depths and of contemporary meteorological factors from 0600 hrs. of 19th February 1935 to 0600 hrs. of 20th February 1935

Time	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700
Percentage moisture at surface	7·0	7·2	6·8	5·9	5·1	4·3	3·7	3·1	2·6	2·7	2·9	3·2
Percentage moisture at 1″ depth	7·6	7·5	7·7	7·5	8·0	8·2	8·3	8·4	8·2	7·9	7·7	7·7
Percentage moisture at 6″ depth	25·7	25·6	25·7	25·0	25·2	25·5	25·0	25·4	25·7	25·8	25·8	25·7
Vapour pressure (0·3″) mm. of Hg.	7·4	7·5	7·9	9·7	11·0	9·0	7·5	6·5	5·8	4·5	2·7	2·7
Vapour pressure (6 ft.) mm. of Hg.	7·8	7·7	7·6	7·4	6·9	5·5	5·0	5·3	5·5	3·8	3·3	3·3
Humidity per cent (0·3″)	65	65	63	52	38	26	20	16	13	10	6	5
Humidity per cent (6 ft.)	66	64	60	52	37	25	19	18	15	12	10	10
Wind speed (in miles per hour)	0·5	0·6	1·0	1·2	1·5	3·6	4·7	4·7	4·4	3·6	2·6	2·1

Time	1800	1900	2000	2100	2200	2300	2400	0100	0200	0300	0400	0500	0600
Percentage moisture at surface	3·5	3·8	4·2	4·6	4·8	4·9	5·1	5·2	5·3	5·3	5·4	5·6	5·9
Percentage moisture at 1″ depth	8·3	8·0	8·0	7·9	7·6	7·3	7·4	7·5	7·7	7·6	7·8	8·0	7·9
Percentage moisture at 6″ depth	25·6	25·3	24·9	24·8	25·5	25·8	25·9	25·9	25·9	25·7	25·5	25·2	25·0
Vapour pressure (0·3″) mm. of Hg.	3·4	3·3	4·0	3·9	4·0	4·1	3·9	3·8	3·5	3·3	3·1	2·8	2·9
Vapour pressure (6 ft.) mm. of Hg.	3·7	3·7	4·0	4·3	4·7	5·1	5·0	4·9	4·8	4·6	4·5	4·4	4·2
Humidity per cent (0·3″)	9	15	19	22	26	29	31	33	34	34	35	35	36
Humidity per cent (6 ft.)	12	15	20	24	32	36	39	42	44	46	47	48	48
Wind speed (in miles per hour)	1·3	1·0	0·8	0·6	0·4	0·3	0·2	0·1	0·1	0·2	0·1	0·1	0·1

TABLE VIII

Diurnal variation of soil-moisture (percentage on dry basis) at different depths and of contemporary meteorological factors from 0600 hrs. of 6th May 1935 to 0600 hrs. of 7th May 1935

Time	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700
Percentage moisture at surface . . .	6·8	6·6	6·4	5·7	5·3	4·7	4·3	4·0	3·7	3·6	3·9	4·2
Percentage moisture at 1″ depth . . .	7·8	7·6	7·6	7·8	7·9	8·0	8·0	7·8	7·7	7·4	7·3	7·0
Percentage moisture at 6″ depth . . .	20·2	20·4	20·7	20·6	20·6	20·5	20·4	20·4	20·6	20·7	21·0	20·3
Vapour pressure (0·3″) mm. of Hg. . .	9·5	10·4	11·5	11·0	9·7	8·3	8·0	7·8	7·2	4·5	4·5	8·0
Vapour pressure (6 ft.) mm. of Hg. . .	10·9	10·5	9·9	9·0	7·7	6·6	6·0	5·4	4·9	4·4	5·0	8·1
Humidity per cent (0·3″)	53	47	34	24	17	11	9	9	7	4	5	12
Humidity per cent (6 ft.)	56	51	35	24	17	13	11	9	8	7	9	16
Wind speed (in miles per hour) . . .	0·5	0·5	0·8	1·5	2·7	3·5	4·2	4·6	5·1	5·3	4·2	5·0

Time	1800	1900	2000	2100	2200	2300	2400	0100	0200	0300	0400	0500	0600
Percentage moisture at surface . . .	4·5	5·0	5·5	5·8	6·1	6·3	6·6	6·8	7·0	7·2	7·3	7·5	7·5
Percentage moisture at 1″ depth . . .	6·8	6·8	6·8	7·0	7·3	7·2	7·4	7·3	7·3	7·5	7·1	7·4	7·6
Percentage moisture at 6″ depth . . .	20·0	20·3	20·6	20·9	21·0	20·9	20·9	20·8	20·7	20·7	20·6	20·6	20·5
Vapour pressure (0·3″) mm. of Hg. . .	14·5	15·7	16·4	16·7	16·9	16·7	16·4	15·8	15·4	14·8	14·4	13·7	13·5
Vapour pressure (6 ft.) mm. of Hg. . .	14·1	17·5	18·5	18·8	18·1	17·2	16·7	16·4	16·0	15·6	15·2	14·9	14·6
Humidity per cent (0·3″)	25	37	46	51	53	54	55	56	56	57	57	57	55
Humidity per cent (6 ft.)	27	40	47	56	56	56	57	57	58	58	58	59	59
Wind speed (in miles per hour) . . .	7·7	8·5	8·5	7·5	6·2	5·6	5·1	4·6	4·2	3·8	3·4	2·8	2·4

Experiments to verify this point were made from 19th to 20th February and 6th to 7th May 1935. Soil samples (in duplicate) were taken simultaneously from the surface, one inch and 6 in. below the surface at two-hourly intervals and their moisture-contents determined in the usual manner. Measurements of the meteorological factors were also made simultaneously, and are given in Tables VII and VIII respectively. The moisture-contents of the soil at the three depths and for different hours on these two occasions are shown in Figs. 6 and 7 respectively. The curves in these figures clearly show that the diurnal variation is insignificant except at the surface.

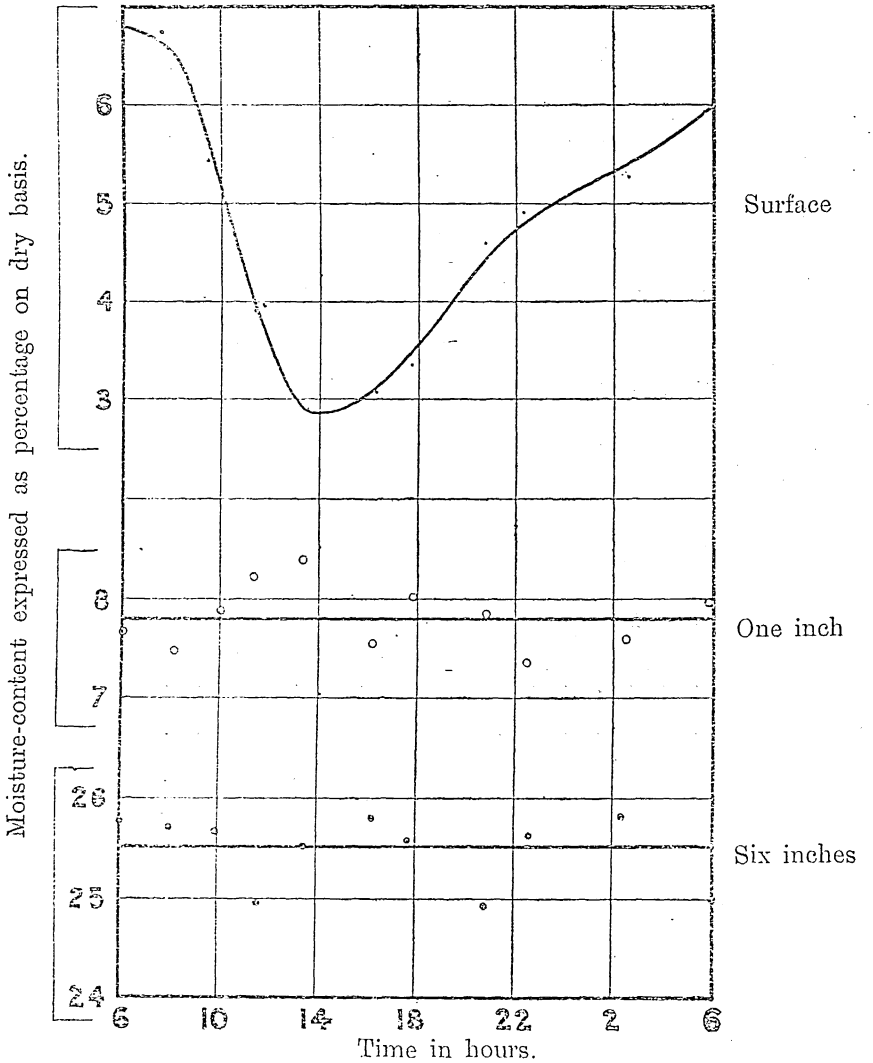


Fig. 6. Hourly variation of moisture-content at "surface", 1" and 6" depths (0600 hours of 19th February 1935 to 0600 hours of 20th February 1935).

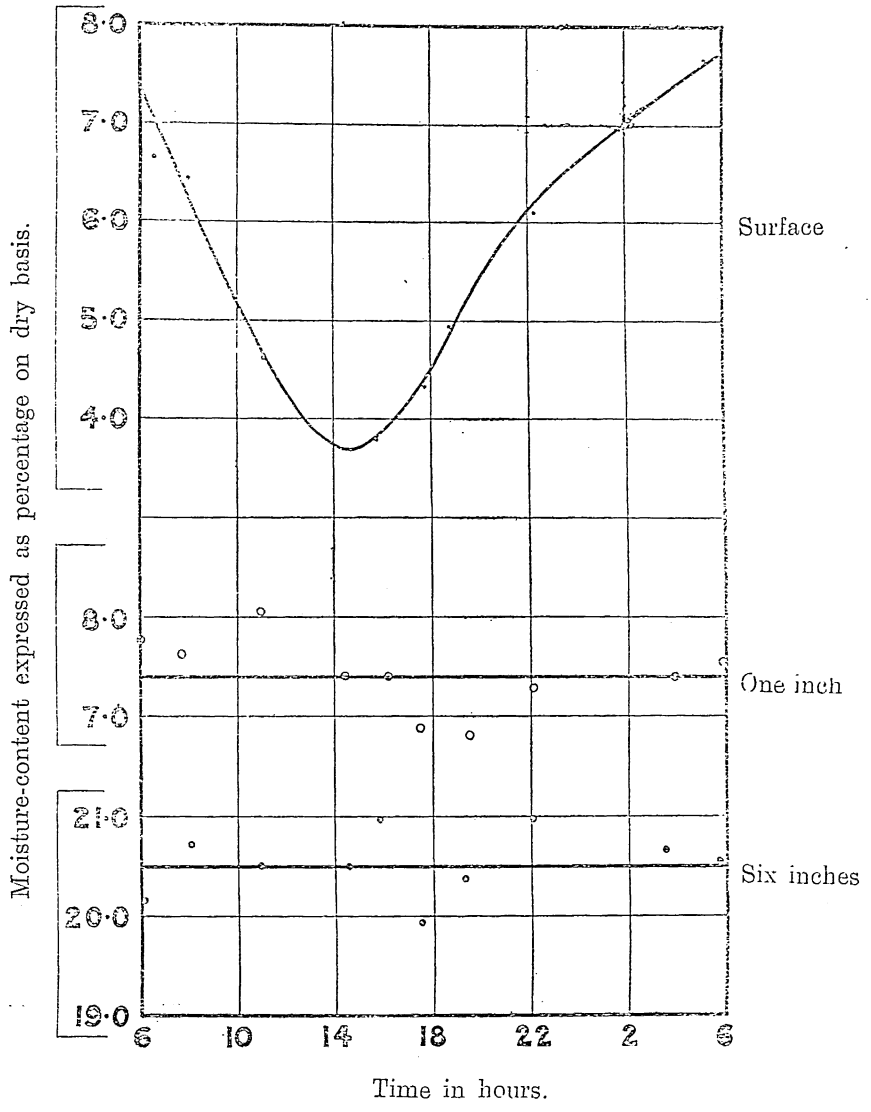


Fig. 7. Hourly variation of moisture-content at "surface", 1", 6" depths (0600 hours of 6th May 1935 to 0600 hours of 7th May 1935).

The soil layers below an inch may, therefore, be assumed to have no influence on the hourly variation of moisture at the surface during the clear season. We are thus concerned in the present discussion mainly with the soil surface and the air layers above it.

It is, of course, to be expected that, in tracts where the water table is very near the surface, *e.g.*, coastal tracts of India and tracts near irrigation canals as in the Punjab and in Sind, the water in the soil below the surface would play a most important role in the moisture balance at the surface of the soil. Phenomena of this type would be quite distinct from what we have been discussing in this paper and deserve a special study.

Section II

The moisture-variation index in relation to other properties of the soil

The results of chemical and mechanical analyses of the main soil types in India are available in the publications of the various agricultural departments. The data are by no means exhaustive or derived according to a common plan or method. Nevertheless, an examination of these data reveals that one of the major variations from soil to soil is in the clay fraction. Table IX gives the results of mechanical analyses of certain typical soils. The table shows that, in general, the alluvial group has a small clay fraction and large silt content, the black soils are rich in clay and poorer in the particles of large size, other soils having intermediate positions in the scale of clay content. It is well known that, the larger the clay fraction or colloidal matter in a medium like the soil, the larger will be the effective area available for absorptive phenomena, so that, in a general way, it is easy to see why black cotton soils should have the largest moisture-variation index.* The study of the moisture-variation index in the case of the different groups of particle sizes would certainly be worth-while in the case of the major soils of India as a special investigation. In the present section we shall confine ourselves to the results of some preliminary experiments on the physical properties of the soils which were made recently at Poona.

TABLE IX

Name of soil types	District	Clay	Fine silt	Silt	Fine sand	Coarse sand	Remarks.
1. Black cotton soils	South Gujarat .	44·4	8·1	26·5	20·7	0·4	
	Jalgaon .	49·1	4·0	17·1	25·6	4·1	Taken from bulletin No. 160, 1929 "Soils of the Bombay Presidency."
	Surat .	32·3	6·4	34·8	26·3	0·2	
	West Khandesh	42·8	8·7	32·1	14·1	4·1	
	Poona .	25·7	8·1	33·3	25·9	7·0	
	Nagpur .	44·4	18·3	12·8	5·5	0·4	Data supplied by Agricultural Department, Central Provinces.
	Akola .	36·9	19·1	15·8	8·5	2·6	
	Wardha .	40·0	21·7	11·2	7·3	0·4	

* "A Study of Absorption of Moisture by Soil" by J. N. Sen, Ph. D., and B. M. Amin, B.A., Memoirs of the Department of Agriculture in India (Chemical Series), Vol. 8, No. 12, 1926, is very interesting in this connection.

TABLE IX—(*contd.*)

Name of soil types	District	Clay	Fine silt	Silt	Fine sand	Coarse sand	Remarks.
2. Laterite and red soils	Poona (from hill sides).	4·0	3·9	19·9	18·3	13·3	From bulletin No. 160, Department of Agriculture, Bombay Presidency.
	Dacca .	28·1	13·5	24·5	21·2	4·0	Data supplied by Agricultural Department, Bengal.
	Mandalay	10·0 22·3 10·8	21·1 16·0 21·0	23·2 23·8 25·9	39·3 33·6 33·1	5·5 4·0 9·2	Taken from Agricultural Survey No. 15 of 1932, Department of Agriculture, Burma.
3. Alluvial soils	Sind .	15·7	8·5	56·1	19·5	0·2	From bulletin No. 160, Department of Agriculture, Bombay Presidency.
	Punjab (average of typical districts).	12·3	21·2	20·7	30·0	12·0	From Memoirs of the Department of Agriculture in India, " Soils of the Punjab ", Vol. X, No. 2.
	Bengal .	14·1	20·5	26·1	27·8	1·24	Data supplied by Department of Agriculture, Bengal.

1. Water-holding capacity

The water-holding capacities of soils from Poona, Sholapur, Hagari, Bangalore, Pusa and Lyallpur were determined with the help of portable drain-gauges designed locally. Plate LXVI is a photograph of this type of drain-gauge which consists of a cylindrical vessel of the required height and 5 inches in diameter (same as that of the standard rain-gauge) to contain the soil and a funnel which drains the water percolating through the soil into a suitable receiver below. The soil rests on a perforated disc at the bottom of the cylindrical vessel.

In our experiments 6″ of each soil were packed uniformly at the mean rate of 17½ oz. per inch of depth. After all the gauges were filled with the different soils, one inch depth of water was poured at the top of the soil at 1400 hrs. daily and any percolated water measured on the succeeding day at the same time. These experiments were continued without break until the soils were saturated with water when they began to drain all the water poured at the top of the soil columns.

The cylindrical vessels of the drain gauges were kept covered carefully to prevent loss of water by evaporation, the covers being removed only momentarily daily once for pouring water.

Table X gives the results of one of these experiments. After pouring one inch of water on the 4th and 5th December 1934, no percolation was noticed through any of the soils. After pouring one inch on the 6th, the Lyallpur soil showed on the 7th at 1400 hours a percolation of 0·88 in., Bangalore 0·69 in., Pusa 0·62

in., and Hagari 0·22 in. The Sholapur and Poona soils still showed no percolation. The addition of one inch on the 7th started percolation in these two also so that, after the 8th, the soils all began to percolate all the water poured at the top. From these results simple subtraction of the total percolation from the total water added during the period of the experiment gives the quantity of water "held" by the soil in each case. The water-holding capacities so measured are expressed as percentage of air-dry soil in Table XI. Here also the black cotton soils top the list.

TABLE X

Date	Depth of water poured into each gauge at 1400 hrs.	Amount of water which had percolated through the soil during 24 hours ending 1400 hours of the next day					
		Sholapur	Poona	Hagari	Pusa	Bangalore	Lyallpur
4th December 1934 . .	One inch	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*
5th December 1934 . .	,,	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*	*Nil*
6th December 1934 . .	,,	*Nil*	*Nil*	0·22″	0·62″	0·69″	0·88″
7th December 1934 . .	,,	0·31″	0·38″	0·99″	0·99″	0·96″	0·96″
8th December 1934 . .	,,	1·00″	0·97″	0·99″	0·99″	0·97″	0·96″

TABLE XI

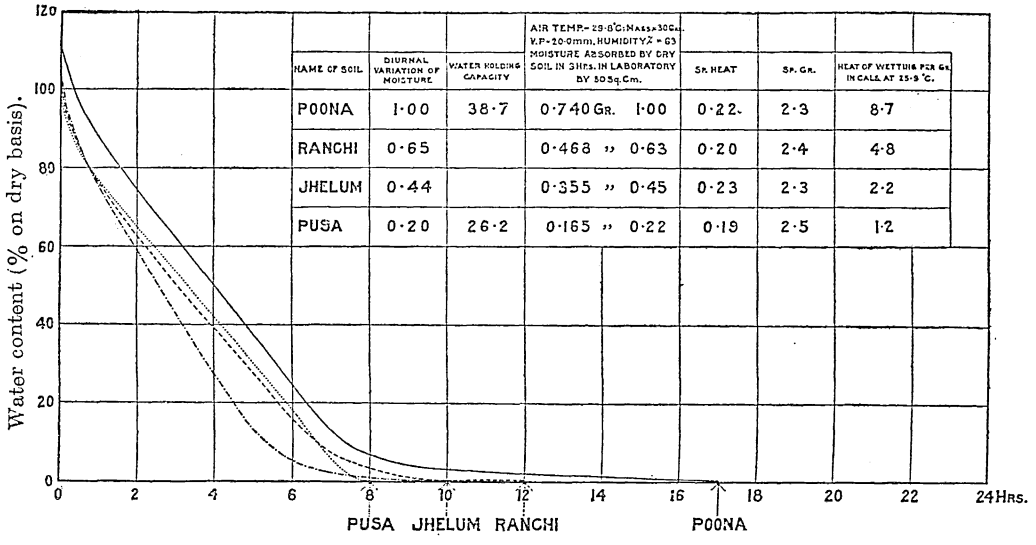
Name of soil	Depth Inches	Amount of soil per inch of depth Oz	Total amount of water (in inches) required for saturation Inches	Water-holding capacity expressed as percentage on air dry basis
Sholapur . .	6	17·5	3·69	41·0
Poona . . .	6	17·5	3·65	38·7
Hagari . . .	6	17·5	2·80	30·9
Pusa . . .	6	17·5	2·40	26·2
Bangalore . .	6	17·5	2·38	24·0
Lyallpur . .	6	17·5	2·20	22·8

2. Rate of drying

For determining the moisture-content of a soil sample, the sample is first weighed and kept in a steam oven until it has lost all the moisture it can give up at 100°C. This is usually verified by weighing until successive weights are

constant. An exact study of the rate of drying in a steam oven should be interesting both from a practical point of view as well as from the point of view of this paper.

Four typical soils, *viz.*, Poona, Ranchi, Jhelum and Pusa soils, were chosen for such a study ; 30 grms. of each of these soils were mixed with about the same weight of water and kept in the steam oven at the same time after weighing initially. The vessels were weighed at hourly intervals, care being taken to keep them air-tight while weighing. The hourly weighings were discontinued in each case after the particular soil had attained a constant minimum weight at 100°C. The rate of drying as well as the total time taken by each of the soils for complete drying at 100°C. will be seen from the curves in Fig. 8. The curves show that, when the soils have about 100 per cent water on dry basis, the rate of drying is rapid until the water content goes down to about 90 per cent. Later, the soils go on drying at a small but uniform rate until the moisture-content decreases to about 5 per cent. Further decrease in the moisture-content takes the least time in the case of the Pusa soil and most time in the case of Poona soil, the other soils taking an intermediate position between these.



NAME OF SOIL	DIURNAL VARIATION OF MOISTURE	WATER HOLDING CAPACITY	AIR TEMP.-29·6°C; Mass×30 Cal. V.P.-20·0mm. HUMIDITY% = 63 MOISTURE ABSORBED BY DRY SOIL IN 3 Hrs. IN LABORATORY BY 30 Sq. Cm.	SP. HEAT	SP. GR.	HEAT OF WETTING PER GR. IN CALS. AT 29·9°C.
POONA	1·00	38·7	0·740 GR. 1·00	0·22	2·3	8·7
RANCHI	0·65		0·468 " 0·63	0·20	2·4	4·8
JHELUM	0·44		0·355 " 0·45	0·23	2·3	2·2
PUSA	0·20	26·2	0·165 " 0·22	0·19	2·5	1·2

Fig. 8. The curves in the figures show the rates of drying of four different types of soils at 100°C. The inset table gives :—

(*a*) the diurnal variation of moisture-content (expressed in terms of Poona =1),

(*b*) the water-holding capacity,

(*c*) the absorption of moisture in 3 hours under steady conditions in the laboratory,

(*d*) the specific heat,

(*e*) the specific gravity, and

(*f*) the heat of wetting of the above soils.

Water content of soil (% on dry basis).

Further experiments indicated that the initially rapid drying is due to evaporation as from a free water surface at 100°C., the later steady but less rapid drying is due to evaporation of the capillary water from the moist soil and the last stage (after about the 5 per cent stage) is due to evaporation of the hygroscopic water. Pusa soil takes eight hours, Jhelum soil ten hours, Ranchi soil twelve hours and Poona soil seventeen hours to attain a steady minimum weight after complete drying at 100 °C. These times are in the same order as the moisture-variation indices given in the inset table of Fig. 8.

3. Rates of absorption of moisture under steady conditions in the laboratory

The experiments described in the first section of this paper were made in the open with soils exposed to the diurnal variations of the various meteorological factors. In order to verify whether the soils would show the same sequence in their power to absorb moisture under the steady conditions inside the laboratory, as they do with respect to their moisture-variation indices in the open, experiments were made with four typical soils, *e.g.*, Poona, Ranchi, Jhelum and Pusa soils. About thirty gr. of each of these soils which had been previously dried completely at 100°C., were exposed after they had attained room temperature to the still air of the laboratory in vessels having an area of cross-section of 30 sq. cms., at room temperature. The air temperature was 29·8°C., the partial pressure of water vapour 20·0 mm. and the percentage humidity 63 per cent. Under these conditions the Poona soil absorbed 0·740 gr. of moisture, the Ranchi soil absorbed 0·468 gr. of moisture, the Jhelum soil absorbed 0·355 gr. of moisture and the Pusa soil 0·165 gr. of moisture in three hours. Expressed in terms of Poona soil equal to 1, these absorption are in the ratio of 1 : 0·63 : 0·45 : 0·22, which is practically identical with the ratio of the moisture-variation indices as given in Table V.

4. Specific gravity

The true specific gravity of soils from Poona, Ranchi, Jhelum and Pusa was determined by the specific gravity bottle method, the liquid used being kerosene. The specific gravity of kerosene was also determined for use in the calculations. The specific gravity of these soils varies between 2·3 and 2·5.

TABLE XII

Name of soil	Specific gravity
Poona soil	2·27
Ranchi soil	2·40
Jhelum soil	2·35
Pusa soil	2·51

5. Specific heat

The specific heats of the same soils were determined by pouring hot water into a calorimeter containing a suspension of about forty grms. of soil in water

(known quantities of soil and water are mixed prior to the experiment and allowed to stand until the heat of wetting is dissipated and room temperature is attained by the mixture). The increase of temperature of the mixture was noted and the specific heat of the soil calculated in the usual manner. The table below gives the values of specific heats of the different soils. We shall have to use these values later in calculating the heat of wetting of the soils (next section).

TABLE XIII

Name of soil	Specific heat
Poona soil	0·22
Ranchi soil	0·20
Jhelum soil	0·23
Pusa soil	0·19

6. Heat of wetting

The heat of wetting with water was determined for soils from Poona, Ranchi, Jhelum and Pusa. Samples of these were heated to dryness at 100°C. and then allowed to cool in air-tight vessels. About thirty grm. of each soil* and water both initially at room temperature (25·9°C.) were mixed quickly in a small calorimeter kept inside a Dewar's flask, and the rise of temperature noted with a sensitive thermometer. The specific heat of the soil having been measured already, and the water equivalent of the calorimeter determined to start with, the heat of wetting per grm. of dry soil was calculated. The estimated heats of wetting are given below :—

TABLE XIV

Name of soil	Heat of wetting per gr. of soil in grm. calories (at 25·9° C.)
Poona	8·7
Ranchi	4·8
Jhelum	2·2
Pusa	1·2

To summarise the results of these experiments [Ramdas and Katti, 1935, 2] it is seen that (excepting of course the specific heat and true specific gravity) the following properties of soils vary in a similar manner (please also see Fig. 8 and the inset table in this connection) :—

(1) Diurnal variation of moisture,

(2) Water-holding capacity,

(3) Absorption of moisture in a definite time interval under steady laboratory conditions, and

(4) Heat of wetting.

* The determinations of absorption, specific gravity, specific heat and heat of wetting were all made with soils which had been passed through a 1 mm. sieve.

Section III

Laboratory determination of the desiccating power of different soils

We have seen that soils, when dry, absorb water vapour from the atmosphere and thus influence the distribution of water vapour in the air layers near the ground. To the meteorologist these results are interesting because the absorption of water vapour by the soil during the night and the evaporation of water from the soil during day time help to explain the observed diurnal variations in the pressure of water vapour. The fact that the diurnal variation of soil-moisture is confined to the first few inches of the soil also explains why a mulch helps to give a blanketing effect to the soil below and to conserve the moisture in the lower layers.*

It would be interesting also to study the efficiency of different soils as desiccating agents under steady conditions in the laboratory. The method adopted was to pass an air current (whose initial humidity was known) above dry soil and to note the decrease of humidity after passage.

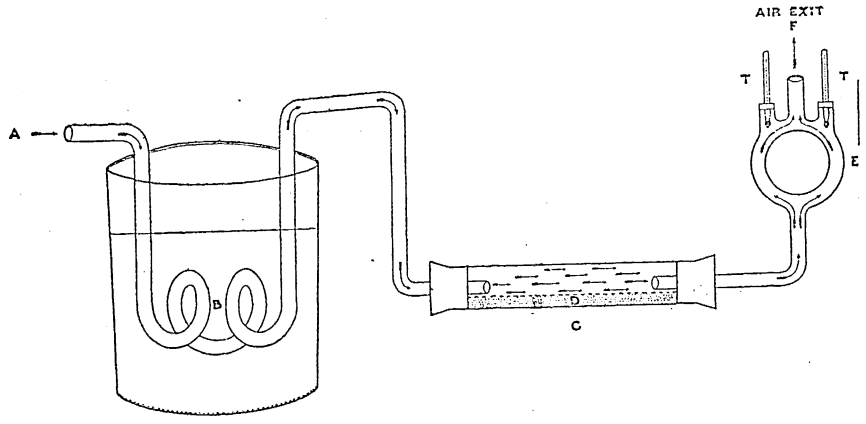


Fig. 9. Apparatus for the measurement of the desiccation of a current of air by different soils.

The experimental arrangement is shown in Fig. 9. The room air compressed by a blower passes into the spiral copper tube B and thence into the tube C which contains the dry soil. The copper spiral B is kept immersed in a water-bath at room temperature so as to maintain the initial conditions constant. This precaution is necessary because the blower gets warmer and warmer as it works and raises the temperature of the air current. After passing through the soil tube

*In this connection please see an interesting article on "The soil as a water reservoir" by T. Eden, *The Tea Quarterly, The Journal of the Tea Research Institute of Ceylon*, Vol. 8, part I, April 1935, p. 31.

C the desiccated air passes into the psychrometer E which has the dry-bulb thermometer T on one side and the wet-bulb thermometer T′ on the other. The thermometers T and T′ are screwed in position and may be removed easily for inspection or for wetting the muslin of the wet bulb thermometer. After passing by the bulbs of T and T′ the air finally emerges at F out into the room. To measure the initial humidity of the air current the tube C is removed and the air passed directly into E. In the initial experiments two psychrometric elements were used, one before and the other after the air current had passed through C, but it was found that the wet bulb of the first would then make the air current entering C more humid than the room air. During the course of the experiment readings of an Assmann Psychrometer were also taken at intervals in the room air outside the apparatus. The tube C was connected only after verifying that the pressure of water vapour in the air current as indicated by E was the same as that indicated by the Assmann Psychrometer. This was achieved by increasing the velocity of the air current in the apparatus until the depression of the wet bulb in E was maximum.

After ensuring that the tube psychrometer would function as efficiently as an Assmann Psychrometer and after recording the initial conditions, the tube C containing a known quantity of soil previously dried at 100°C. and spread uniformly along the tube, was inserted. Almost immediately the wet bulb T′ began to fall and within a few minutes attained a steady low value. The dry bulb T did not undergo any variation whatever as the heat of adsorption in the tube C was dissipated rapidly. The extent of the fall in T′ indicates the desiccating effect of the soil in C. The readings of T and T′ were recorded at short intervals of time until the soil in C was exhausted and T′ began to rise and ultimately attained the initial value again. The maximum fall of T′ as well as the time it took to regain the initial value differed from soil to soil, being large in the case of the black cotton soils and small in the case of soils of the alluvial type.

The velocity of the air current was measured during the experiment by noting the time taken for the displacement of a known volume of water. Also, the weight of soil in the tube C was noted both at the commencement and at the end of each experiment.

These experiments were performed with four soils, *viz.*, soils from Poona, Jalgaon, Bangalore and Lyallpur. For comparing the desiccating power of these soils with that of a standard substance the experiment was also repeated with a sample of "Sorbsil" supplied by the Cambridge Instrument Company. Tables XV to XIX give the full experimental details for the different substances in the order in which they are mentioned above.

TABLE XV

Poona soil

Time in minutes	Temperature and humidity of air current				Temperature and humidity of room air (with Assmann Psychrometer)				Other details
	Dry bulb T °C.	Wet bulb T′ °C.	Humidity percentage	Vapour pressure in mm.	Dry bulb °C.	Wet bulb °C.	Humidity percentage	Vapour pressure in mm.	
0	23·3	14·5	37	8·0	23·8	14·6	36	7·9	
½	23·3	13·8	33	7·1	..	..	..	..	Weight of dry soil before passing air = 11·380 grms.
1	23·3	11·5	21	4·4	..	..	..	..	
1½	23·3	10·2	14	2·9	..	..	..	..	Weight of dry soil after passing air = 12·030 grms.
2	23·3	9·5	10	2·2	..	..	..	..	
3	23·3	9·0	8	1·6	..	..	..	..	Weight of water vapour absorbed by the soil . = 0·650 grm.
5	23·3	8·9	7	1·5	24·3	15·0	36	8·1	
8	23·3	8·9	7	1·5	..	..	..	..	Velocity of air current . . = 43·8 c.c. per second.
10	23·3	9·0	8	1·6	..	..	..	..	
14	23·2	9·3	9	1·8	..	..	..	..	
18	23·3	9·7	10	2·2	..	..	..	..	
24	23·4	10·4	14	3·0	..	..	..	..	Diameter of tube C = 1·3 cm.
30	23·4	10·9	16	3·5	..	..	..	..	Length of tube C = 1 metre.
35	23·8	11·4	18	3·9	..	..	..	..	Fraction of volume of C actually occupied by the soil $= \frac{1}{10}$
40	23·8	11·8	20	4·4	24·5	15·0	35	8·0	
50	24·0	12·0	23	5·2	..	..	..	..	
60	23·9	13·2	27	6·0	..	..	..	..	
70	24·3	13·8	29	6·6	..	..	..	..	
80	24·5	14·2	30	7·0	25·0	14·8	32	7·5	
90	24·8	14·5	31	7·2	25·2	14·4	29	6·9	

TABLE XVI

Jalgaon soil

Time in minutes	Temperature and humidity of air current				Temperature and humidity of room air (with Assmann Psychrometer)				Other details
	Dry bulb T °C.	Wet bulb T′ °C.	Humidity percentage	Vapour pressure in mm.	Dry bulb °C.	Wet bulb °C.	Humidity percentage	Vapour pressure in mm.	
0	25·3	15·1	32	7·8	25·2	15·2	33	8·0	Weight of dry soil before passing air = 11·710 grms.
1	25·3	12·5	18	4·5	..	..	..	..	
1½	25·3	11·2	12	2·9	..	..	..	..	Weight of dry soil after passing air = 12·280 grms.
2	25·3	10·7	10	2·3	..	..	..	..	
3	25·3	10·3	8	1·9	25·4	15·2	32	7·9	Weight of water vapour absorbed by the soil . = 0·570 grm.
4	25·3	10·2	7	1·8	..	..	..	..	
5	25·3	10·2	7	1·8	..	..	..	..	
6	25·2	10·3	8	1·9	..	..	..	..	Velocity of air current . . = 43·8 c.c. per second.
8	25·2	10·5	9	2·2	..	..	..	..	
10	25·2	10·6	10	2·3	..	..	..	..	
20	25·2	11·3	13	3·1	25·6	15·5	33	8·2	Diameter of tube C. = 1·3 cm.
25	25·2	11·6	14	3·4	..	..	..	..	Length of tube C . = 1 metre.
30	25·4	12·1	16	3·9	..	..	..	..	Fraction of volume of C actually occupied by the soil. = $\frac{1}{10}$
35	25·4	12·3	17	4·2	..	..	..	..	
40	25·4	12·9	20	4·9	..	..	..	..	
50	25·8	13·8	23	5·8	..	..	..	..	
60	25·8	14·4	27	6·6	..	..	..	..	
70	25·8	15·0	30	7·4	..	..	..	..	
80	26·2	15·5	31	7·9	26·0	15·4	31	7·8	

TABLE XVII

Bangalore soil

Time in minutes	Temperature and humidity of air current				Temperature and humidity of room air (with Assmann Psychrometer)				Other details
	Dry bulb T °C.	Wet bulb T′ °C.	Humidity percentage	Vapour pressure in mm.	Dry bulb °C.	Wet bulb °C.	Humidity percentage	Vapour pressure in mm.	
0	25·0	14·1	28	6·6	24·8	14·0	29	6·6	Weight of dry soil before passing air = 11·340 grms.
½	25·0	13·2	23	5·5	..	..	..	..	Weight of dry soil after passing air = 11·370 grms.
1	25·0	11·8	16	3·8	..	..	..	..	Weight of water vapour absorbed by the soil . = 0·030 grm.
1½	25·0	11·6	15	3·5	..	..	..	..	
2	24·8	11·4	15	3·5	..	..	..	..	Velocity of air current . . = 43·8 c.c. per second.
3	24·8	11·8	17	3·9	..	..	..	..	
4	24·8	12·3	19	4·5	..	..	..	..	Diameter of tube C = 1·3 cm.
5	24·8	13·0	23	5·3	..	..	..	..	Length of tube C = 1 metre.
6	24·8	13·4	25	6·0	..	..	..	..	Fraction of volume of C actually occupied by the soil. = $\frac{1}{10}$
7	24·8	13·8	27	6·3	..	..	..	..	
8	24·8	14·0	28	6·6	..	..	..	..	
10	24·8	14·2	29	6·8	24·8	14·0	29	6·6	

TABLE XVIII

Lyallpur soil

Time in minutes	Temperature and humidity of air current				Temperature and humidity of room air (with Assmann Psychrometer)				Other details
	Dry bulb T °C.	Wet bulb T′ °C.	Humidity percentage	Vapour pressure in mm.	Dry bulb °C.	Wet bulb °C.	Humidity percentage	Vapour pressure in mm.	
0	25·4	14·0	26	6·3	25·5	14·3	27	6·6	Weight of dry soil before passing air = 11·400 grms.
½	25·4	13·0	21	5·0	..	..	..	..	
1	25·4	12·0	16	3·8	..	..	..	..	Weight of dry soil after passing air = 11·427 grms.
1½	25·4	11·7	14	3·5	..	..	..	..	Weight of water vapour absorbed by the soil . = 0·027 grm.
2	25·4	12·0	16	3·8	..	..	..	..	
3	25·4	12·3	17	4·2	..	..	..	..	Velocity of air current . . = 43·8 c.c. per second.
4	25·4	12·8	20	4·8	..	..	..	..	
5	25·4	13·3	22	5·4	..	..	..	..	Diameter of tube C = 1·3 cm.
6	25·4	13·7	24	5·9	..	..	..	..	Length of tube C = 1 metre.
7	25·4	14·0	26	6·3	..	..	..	..	Fraction of volume of C actually occupied by the soil. = $\frac{1}{10}$
8	25·4	14·1	26	6·4	25·4	14·2	27	6·5	

Table XIX

Sorbsil

Time	Temperature and humidity of air current				Temperature and humidity of room air				Other details
	Dry bulb °C.	Wet bulb °C.	Humidity percentage	Vapour pressure in mm.	Dry bulb °C.	Wet bulb °C.	Humidity percentage	Vapour pressure in mm.	
0	30·5	17·7	27	8·8	30·5	17·6	26	8·6	
½ min.	30·4	15·5	17	5·7	..	..	..	..	Weight of dry sorbsil before passing air . . =12·000 grms.
1 min.	30·3	14·3	13	4·2	..	..	..	..	
2 min.	30·3	13·5	10	3·2	..	..	..	..	Weight of sorbsil after passing air =13·430 grms.
3 min.	30·3	13·3	9	2·9	..	..	..	..	Weight of water vapour absorbed by sorbsil . =1·430 grms.
5 min.	30·3	13·6	10	3·3	..	..	..	..	
8 min.	30·3	13·7	11	3·5	..	..	..	..	Velocity of air current . . =43·8 c.c. per second.
12 min.	30·4	14·0	12	3·8	..	..	..	..	
20 min.	30·5	14·2	12	4·0	..	..	..	..	Diameter of tube C =1·3 cm.
26 min.	30·9	14·5	12	4·2	31·1	17·5	24	8·2	Length of tube C =1 metre.
30 min.	30·7	14·7	13	4·4	..	..	..	..	Fraction of volume of C actually occupied by sorbsil $=\frac{4}{25}$
36 min.	30·5	15·0	15	5·0	30·7	17·6	26	8·5	
42 min.	30·6	15·1	15	5·1	..	..	..	..	
48 min.	30·8	15·3	16	5·4	31·1	17·5	24	8·2	

1 hour 4 min.	31·3	15·6	16	5·4	..	..	..	..
1 hour 16 min.	30·7	15·8	18	6·0	..	..	..	..
1 hour 33 min.	31·0	16·2	19	6·4	..	..	..	..
1 hour 43 min.	31·0	16·3	19	6·5	..	..	..	..
1 hour 53 min.	31·1	16·5	20	6·8	31·5	17·3	22	7·7
2 hours	31·2	16·7	21	7·0	..	..	..	..
2 hours 10 min.	31·5	16·8	21	7·3	..	..	..	..
2 hours 20 min.	31·2	16·9	21	7·3	31·5	17·0	21	7·3
2 hours 30 min.	31·2	16·9	21	7·3	..	..	..	..
2 hours 40 min.	31·3	16·9	21	7·3	..	..	..	..
2 hours 50 min.	31·3	16·9	21	7·3	31·5	17·0	21	7·3

The velocity of the air current was adjusted so as to allow 43·8 c.c. of air per second to pass through the apparatus. After passage above the soil exposed in the drying tube C, the wet bulb temperature rapidly fell in the first few minutes and slowly rose again. Each experiment was concluded as soon as the air current ceased to be desiccated, *i.e.*, as soon as the soil had got exhausted and no longer absorbed any moisture from the air current. When this stage was reached the humidity of the air current was practically identical with that of the room air outside the apparatus.

In the case of Poona and Jalgaon soils and of sorbsil, the time taken for completely exhausting the desiccating power was of the order of 80 to 150 minutes. During the interval the room air sometimes underwent a slight change in its moisture content, but such change was invariably small when compared to the changes of vapour pressure and humidity experienced by the air current on passing through the soil in the tube C.

A decrease in the vapour pressure by 1 mm. of mercury corresponds to a loss of 10^{-6} grm. of water vapour per cubic centimetre or to one grm. of water vapour per cubic metre of air. If we plot the values of vapour pressure against time we shall be able to calculate from the area of the curve and the velocity of the air current in cubic centimetres per second, the total mass of water vapour extracted from the air current by the soil. For example, if A is the area of the curve when the vapour pressure is expressed in mm. of mercury and time in minutes and if V is the volume of air in c.c. entering the tube C per second, the mass of water vapour absorbed in grms. is given by :

$$A \times 60 \times V \times 10^{-6}.$$

TABLE XX

Name of soil	Wet bulb temperature in °C.			Humidity percentage			Vapour pressure (mm. of Hg.)			Time taken for attaining minimum value in minutes (t_1)	Time taken for completely exhausting the drying power of the soil in minutes (t_2)	Moisture gained by soil			Velocity of air current in cubic centimetres per second	Total volume in cubic metres of air passed over soil during the experiment ($V \times t_2$)	Mass of water lost by the air (actual dehydration) (grm.)	Amount of dehydration of air expressed in grammes per cubic metre	Mass of soil required to produce the observed dehydration in one cubic metre of air (grms.)
	Initial value	Minimum value	Maximum decrease caused by soil	Initial value	Minimum value	Maximum decrease caused by soil	Initial value	Minimum value	Maximum decrease caused by soil			Dry weight (M) of soil in grammes	Mass of water (m) absorbed in grammes	Expressed as percentage of dry weight of soil					
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
Poona . . .	14·5	8·9	5·6	37	7	30	8·0	1·5	6·5	6·0	90	11·380	0·650	5·7	43·8	·236	0·730	3·09	48·12
Jalgaon . .	15·1	10·2	4·9	32	7	25	7·8	1·8	6·0	5·0	80	11·710	0·570	4·9	43·8	·210	0·620	2·95	55·71
Bangalore . . .	14·1	11·4	2·7	28	15	13	6·6	3·5	3·1	2·0	10	11·370	0·030	0·3	43·8	·026	0·030	1·14	379·00
Lyallpur . .	14·0	11·7	2·3	26	14	12	6·3	3·5	2·8	1·5	8	11·400	0·027	0·2	43·8	·021	0·027	1·29	542·86
Sorbsil . . .	17·7	13·3	4·4	27	9	18	8·8	2·9	5·9	3·0	150	12·00	1·430	11·7	43·8	·394	1·740	4·41	30·44

This value can be compared with the actual increase in weight of the soil at the end of the experiment.

The vapour pressure-time curves are shown in Fig. 10. Sorbsil is an efficient absorber, and retains its power to absorb for the longest time. Next in order come the soils from Poona, Jalgaon, Bangalore and Lyallpur, respectively. The last two cause only a small depression in the wet-bulb temperature and the vapour pressure, and, even so, get exhausted within ten minutes. In all cases the dehydration of the air current is rapid and the vapour pressure attains its minimum value within a few minutes after the commencement of the experiment ; thereafter the vapour pressure slowly increases and becomes equal to that of the air outside.

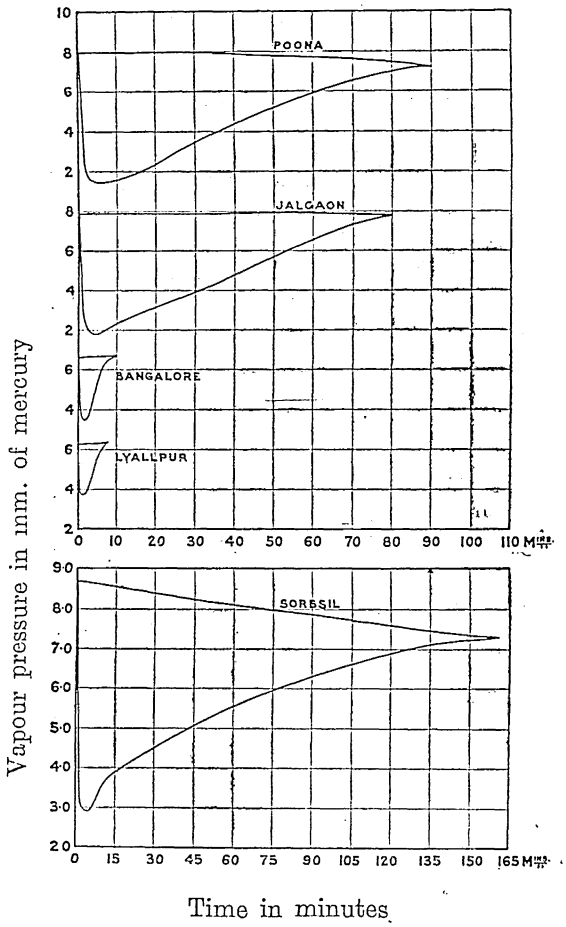


Fig. 10. Curves showing the variation of vapour pressure with time in the case of different soils and sorbsil; the straight lines at the top of each curve shows the vapour pressure in the room air outside the apparatus.

The results which may be deduced from Tables XV to XIX and from the curves in Fig. 10 are summarised in Table XX where, for facility of reference, the columns are numbered serially. Columns (2) to (10) give the initial and minimum values as well as the differences between these values in the case of the wet-bulb temperature, humidity percentage and the pressure of water vapour, in the experiments with the four soils and with sorbsil. Column (11) gives t_1 the time taken for attaining the minimum value and column (12) gives t_2 the total time taken for completely exhausting the absorbing power of each of the above substances. Column (13) gives the actual mass M of the substances used in the different experiments; this is usually between eleven and twelve grammes. Column (14) gives the mass of water vapour m absorbed in t_2 minutes. Column (15) gives the value of $\frac{m}{M} \times 100$. Column (16) gives the velocity V, of the air current which was adjusted to be 43·8 c.c. per second in all the experiments. Column (17) indicates the total volume of air which passed through the tube C in t_2 minutes. This volume is expressed in cubic metres. The next column (18) gives the mass of water lost by the air as calculated from the curves in Fig. 10 ($A \times 60 \times V \times 10^{-6}$). These values may be compared with the values of m in column (14). There is fairly good agreement in the values. The mass of water lost by the air can also be expressed in grms. per cubic metre (column 19). In the last column (20) is given the mass of soil required to desiccate one cubic metre of air to the extent indicated in column (19). From column (20) we note that with about fifty grms. of dry Poona soil we can remove about three grms. of water from one cubic metre of damp air. These figures do suggest that the black cotton soils may be used with profit for keeping the air in an enclosed space dry. The cost involved would be negligible when compared to that of common drying agents like sulphuric acid, calcium chloride, phosphorous pentoxide, etc. Further experiments to make practical use of the above results are in contemplation.

The investigations described in the preceding sections are intended to provide a general survey of this subject. The soils have been studied more or less as they exist in nature and there is ample scope for further investigations with the various constituents of each soil which may be separated by mechanical as well as chemical analysis. It would also be interesting to carry on the investigations on the moisture-variation index with each soil in its own natural environment, *e.g.*, Pusa soil at Pusa, Lyallpur soil at Lyallpur and so on.

In conclusion the authors desire to express their best thanks to the Director-General of Observatories for facilities given at the laboratories of the Meteorological Office at Poona. This investigation was made in the Agricultural Meteorology Section (India Meteorological Department) financed by the Imperial Council of Agricultural Research.

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Precision Observations on Weather and Crops

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THE earlier researches of Lawes and Gilbert,[1] Shaw,[2] Hooker[3] and others have shown that forecasts of crop acreage and yields can be made on the basis of weather factors. Where adequate data exist such forecasts may be more accurate than those arrived at by the subjective methods used in the official forecasts of most countries. Pioneer work of this nature has been done in India by Jacob[4] and Unaker.[5]

In India, while the official statistics of area sown to different crops are fairly accurate, the data of yield per acre are not so satisfactory. The information collected in the past regarding the various agricultural and meteorological factors concerned has been limited to very rough estimates of the final yield over large areas on the one hand and to certain observations on the "macro" or general climate at the few observatories of the India Meteorological Department on the other. The yield data of the Government Experimental Farms in different provinces are, with a few exceptions, available only for short periods, and systematic climatological data have rarely been maintained.

While some interesting general relationships can be established with these past data,* it is necessary to ensure the collection of more complete information in future years. This involves the recording side by side of systematic, detailed and uniform data of the climatic factors in the actual environment of a crop as well as the life-history of the crop during the growing season. Such information will enable us to study crop weather relationships in all their aspects.

The British Agricultural Meteorological Committee (*vide* Report of the Conference of Empire Meteorologists, 1929, Agricultural Section) having realised the importance of this aspect of Agricultural Meteorology, outlined a detailed scheme called the "Precision Scheme" with a view to record detailed observations on a few crops, according to a specified sampling technique. Our experience at Poona with the micro-climates of different crops [6, 7, 8, 9] suggested that such a scheme to be complete should also include detailed observations of the micro-climate.

In order to develop all the details of a combined "Weather and Crop Precision Scheme" which would be suitable for Indian conditions, the Agricultural Meteorology Branch prepared a draft scheme which was circulated in order to elicit detailed criticisms and suggestions from the various agricultural departments and crop specialists. Their suggestions and remarks have been very valuable in revising the scheme. In order to gain actual working experience of the scheme as well as to decide upon the sampling technique suitable for Indian crops, the Agricultural Meteorology Branch also started precision observations on wheat and jowar at Poona, on rice at Karjat in collaboration with the Crop Botanist, and on Bajri at Baroda in collaboration with the Superintendent of the Baroda Experimental Farm. Some very interesting results have been obtained as regards the stand, growth and yield of these crops. The results in the case of wheat alone are briefly indicated here.

In Table I is given the frequency distribution of the number of plants per quarter metre on the 26th February 1934, observed in 160 quarter metre unit lengths of drill selected according to the sampling technique for wheat.

It is interesting to observe the very wide range of fluctuation of plant density. The estimated average number of plants per

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* Please see a recent note entitled "Influence of Weather and Prices on the Cotton Crop of the Bombay Presidency," by R. J. Kalamkar in *Curr. Sci.*, 1936, **4**, 484.

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TABLE I.

Frequency Distribution of Number of Plants per Quarter Metre Lengths (26th February 1934).

Number of plants per quarter metre	Frequency
0	27
1	36
2	44
3	24
4	19
5	8
6	1
7	0
8	0
9	1

metre, assuming 80% germination in the laboratory would be as high as 41 at a seed rate of 53 lbs. per acre (distance between rows being 12") while at harvest it was as low as 8, the reduction under field conditions being due to interculturing, mechanical injury to plants due to soil cracking and to other damages such as nibbling by rats, etc.

Table II shows the developmental stages of the wheat crop.

A maximum shoot-plant ratio of 5·3 was reached by the middle of December which by harvest time was reduced to 4 on account of the dying off of late formed tillers about the middle of December. More than 50% of the shoots had put forth ear-heads by the middle of January and about 90% by harvest time. The average number of ears per plant at harvest was 3·5. The yield of grain and straw per metre length as estimated by sampling was 25·5 gms. and 49·0 gms. respectively while the actual yields were 23·3 and 50·5 gms. respectively.

Such quantitative measurements of plant growth enable us to determine the principal events which mark the progress of the crop from germination to maturity and if the observations are made in a similar manner at a number of centres over a long series of years, it will be possible to study crop-weather relations in all their aspects.

In conclusion the writers wish to express their best thanks to Dr. L. A. Ramdas, Agricultural Meteorologist for his suggestions during the course of this investigation.

TABLE II.

Developmental Stages of the Wheat Crop.

Date	Plants per metre	Shoots per metre	Shoot : plant ratio	Height in cm.	Number of green leaves per plant	Number of ear heads per metre	General Remarks
5th Nov. 1933	15·7	27·5	1·75	2·51	2·94		(1) Sowing was done on 14th October. Germination was complete by 21st October 1933.
13th Nov. 1933	13·8	44·8	3·25	3·74	3·73		
18th Nov. 1933	13·9	56·9	4·10	4·68	3·55		(2) Interculture with slit-hoe on 22nd November 1933.
25th Nov. 1933	11·9	56·7	4·77	6·34	4·24		
2nd Dec. 1933	10·0	51·9	5·17	7·55	4·78		(3) Cracking of soil observed on the 9th December 1933. Lower leaves turning yellow and found drying by the end of December.
9th Dec. 1933	9·2	47·5	5·17	10·05	5·19		
16th Dec. 1933	8·9	45·8	5·30	13·88	5·56		(4) Rust noticed on the 13th January 1934.
23rd Dec. 1933	9·4	42·9	4·55	23·83	5·60		
30th Dec. 1933	10·4	47·0	4·52	31·01	5·74	1·5	(5) Crop harvested on the 26th February 1934.
6th Jan. 1934	9·8	38·8	3·98	38·82	5·28	7·7	
13th Jan. 1934	8·8	36·4	4·12	46·88	5·00	19·8	
20th Jan. 1934	9.2	36·7	4·00	..	..	25·4	
26th Feb. 1934	8·2	32·2	3·94	50·20	..	29·0	

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